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MEDICAL DEPARTMENT
UNITED STATES ARMY
IN WORLD WAR II

MEDICAL DEPARTMENT, UNITED STATES ARMY

SURGERY IN WORLD WAR II

ORTHOPEDIC SURGERY in the ZONE OF INTERIOR

Prepared and published under the direction of
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The Surgeon General, United States Army

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OFFICE OF THE SURGEON GENERAL

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ORTHOPEDIC SURGERY

in the

ZONE OF INTERIOR

MEDICAL DEPARTMENT, UNITED STATES ARMY

The volumes comprising the official history of the Medical Department of the United States Army in World War II are prepared by The Historical Unit, U.S. Army Medical Department, and published under the direction of The Surgeon General, U.S. Army. These volumes are divided into two series: (1) The administrative or operational series; and (2) the professional, or clinical and technical, series. This is one of the volumes published in the latter series.

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Foreword

The publication of this volume on Orthopedic Surgery in the Zone of Interior concludes another, and a most important, subseries in the official history of the U.S. Army Medical Department in World War II. Quantitatively, wounds of the extremities exceeded all other wounds, and patients with complaints referable to the feet and lower back occupied an inordinate amount of bedspace as well as an inordinate amount of time and effort on the part of medical and paramedical personnel.

Previously published volumes in this orthopedic subseries covered this field (1) in the Mediterranean theater, where the management of such injuries was evolved, after an unfortunate beginning on a trial-and-error basis, and (2) in the European theater, where the policies evolved in the Mediterranean theater were put into practice on a massive scale and with brilliant success.

The third volume in the subseries deals with the final stage of the phased management of combat wounds and with the bulk of noncombat conditions. It also deals with administrative matters. The editors apologize for the inclusion of these details, but their apologies are unnecessary for, in the Army, standardization is the basis of all therapy.

Included in the administrative section of the volume are other equally important matters; such as, the development and selection of equipment, the organization of hospital sections for specialized treatment, the functions and activities of consultants, and the training of medical personnel to supply the desperate need for orthopedic surgeons (an undesirable plan theoretically, but one which worked and which fulfilled its objective remarkably well). All of these administrative considerations helped to implement the mission of the Medical Department, which is to preserve the fighting strength of the Army.

I should like to reemphasize two other considerations which the editors of this volume also emphasize:

First, the importance in military circumstances of conditions which, in civilian life, would be no more than trivial or inconvenient. Among these conditions are carpal scaphoid fractures; march fractures; complaints referable to the feet and lower back; and certain lesions of the knee, particularly when ill-advised operations were done on them. The manpower losses which these various conditions caused were anything but trivial.

Second, the frankness and candor with which this volume, like all other volumes in this historical series, has been written. The entire series is more valuable because it is based on this concept.

I am greatly pleased with how well the (relatively) new oral history

technique contributes to this volume. I am familiar enough with the material it contains to realize how much of it was supplied by this means and how freshly and vividly it fits into the total picture. There is now a general realization of the value of this method, and I am happy that it has been employed in so many of the volumes of this series.

I have noted in forewords to previously published volumes of this historical series that one of my predecessors, the late Maj. Gen. Merritte W. Ireland, considered the completion of medical history of World War I perhaps the most important achievement of his tour of duty in this office. I know, too, that my immediate predecessor, Lt. Gen. Leonard D. Heaton, considers the medicomilitary histories published in recent years as major contributions to the medical literature and perhaps our most lasting contribution. I fully subscribe to this theory and it gives me great satisfaction that the Historical Unit of the Army Medical Department has continued to record the major activities (both clinical and administrative) of the Medical Department, and to publish the results thereof, during my term of office.

Dr. Mather Cleveland and Dr. Alfred R. Shands, Jr., both formerly Colonel, MC, contributed greatly to the active war effort. They have added to these endeavors the editorial work of this volume, as well as numerous contributions to the text. My grateful appreciation is due to them; to the authors of various chapters; to others who contributed data and helpful advice and criticism; and to the personnel of the Historical Unit, USAMEDD, which did the final editorial work on this volume.

HAL B. JENNINGS, Jr., M.D.
Lieutenant General, United States Army,
The Surgeon General.

Preface

This volume is the third (and final) in the orthopedic subseries in the history of the U.S. Army Medical Department in World War II and the thirty-seventh to be published in the official account of that department in that war.

The first volume in this subseries, which appeared in 1956, dealt with orthopedic activities in the European Theater of Operations. The second volume, in 1957, dealt with the same activities in the Mediterranean theater.

The present volume deals with orthopedic surgery in the Zone of Interior.

When effective planning for this and other volumes of the World War II history finally began in 1954, such material as had then been collected for it was reviewed and evaluated. Next, former medical officers who were particularly knowledgeable in special areas were requested to provide material for those areas, using their recollections as well as such recorded data as they might possess. What they originally submitted was expanded further by investigation of leads and by questions and answers, some obtained in writing but a great deal of it obtained by face-to-face sessions—a so-called oral history plan.

Both historically and medically, this plan has worked out very satisfactorily in this volume as in other volumes in this historical series. As the lists of references appended to the various chapters show, ample documentation exists in many fields. But careful reading of the book will also show that there are many areas in which there is no documentation at all, but in which the data are equally valid. They comprise the thoughtful recollections of the orthopedic surgeons who witnessed, or participated in, the events described and who, in many instances, helped to create them. These officers speak from the highest possible authority. They were there, and they had the training and experience, originally or acquired, to evaluate the events they witnessed and have recorded.

The orthopedic casualties who made up so large a proportion of the injured received in Zone of Interior hospitals in World War II came from all theaters and had been treated overseas, particularly early in the war, by surgeons of all grades of knowledge, training, and experience. The record of these casualties in this volume is based on individual and composite clinical experience; special studies; and the observations and comments of medical officers who handled many of them themselves, who supervised the management of many others, and who, no matter at what level they started their military orthopedic careers, ended the war highly knowledgeable in this field. The material thus collected and presented is

bound together by the observations and comments of the editors, who themselves participated actively in the orthopedic experiences.

The consultants in the various specialties, including orthopedic surgery, went far beyond the early concept of their functions. They took part in evaluating personnel, suggested and supervised their assignments, assisted in the organization of centers for specialized treatment, directed training courses, approved or disapproved equipment, standardized therapy, disseminated information, helped to establish surgical standards, and corrected surgical and administrative errors.

It was a stroke of good fortune that, during a large part of the war, the Surgeon General of the Army was Maj. Gen. Norman T. Kirk, an experienced orthopedic surgeon, who fully understood the needs of this specialty and was most sympathetic to these consultants.

This volume, like all the other historical volumes, was written with a twofold intent. The first was to record the events of orthopedic surgery as they occurred in the Zone of Interior. The second was to record those events not only in detail but so frankly and so candidly that the orthopedic errors made in World War II would not be repeated in later wars. The second of these purposes, negative though it be, is in some ways the more important of these objectives.

All medical care in the Army must be carried out in the light of the mission of the Medical Department, which is to preserve the fighting strength of the Army. A recollection of this mission will clarify a number of apparent anomalies in this volume. One is the amount of space given over to conditions which in civilian life would be less important. In military practice, however, such conditions as march fractures, carpal scaphoid fractures (particularly if they were misdiagnosed or mistreated), and certain lesions of the knee (particularly if they were operated on with unsound indications) were of major importance because of the organizational disruption and the manpower losses they caused, not to mention the prolonged bed occupancy and the time of the professional personnel which they required.

As for elective orthopedic surgery, long before the war ended, it was clearly evident that it had been a great mistake to induct men with EPTI (existent prior to induction) defects in the hope of correcting these defects in the service. Unless a soldier could be restored to full combat duty, he was, in general, not useful to the Army.

In military practice, the basis of all therapy is standardization. The individual desires and techniques of the medical officer cannot be permitted for a number of reasons. Perhaps the most important is that the wounded casualty must be evacuated farther and farther to the rear and, at each stage, is under the care of a different surgeon, each one of whom must be able to assume that, in certain forms of injury, certain procedures have been carried out earlier.

Therapy in wartime is primarily a matter of logistics. It depends not only upon what the wounding agent has achieved (that is, the nature and extent of the resulting wound), but it also depends upon the timelag; the transportability of the casualty; the specialized skills of available medical personnel; and the military circumstances, including available transportation.

Previously published volumes in this historical series, including the two orthopedic surgery volumes, have been generously reviewed quantitatively in the medical press and, with very few exceptions, have also been reviewed favorably. The criticisms and suggestions of the reviewers, in a number of instances, have been acted upon in the preparation of this volume. Misconceptions on the part of some reviewers and other readers, however, explain the inclusion of the following explanatory notes:

1. This book is a history, whose frame of reference is limited still further by the fact that it is, first of all, a chronicle or record of events. It was written by medical officers who were clinicians, not by professional historians, who very seldom are clinicians or are clinically informed.

2. This is not a textbook in any sense of the word. Current policies and techniques are not part of its intent. The authors and editors, however, all of whom were in service, would be the first to agree that their civilian practices frequently were altered by their military experiences.

3. To carry out the purposes of this volume, it was often necessary to write in considerable detail a plan which does not make for exciting reading but which was, nonetheless, necessary. If some sections seem extremely elementary, it must be remembered that, for example, the sulfonamides had come into general use only just before the war and that the war was almost half over before penicillin came into general use. The use of these agents in warfare was a truly pioneer experience, and the forms available and the techniques used in wartime orthopedic surgery require a detailed historical record. Many of them bear little or no resemblance to the forms and techniques of the present (1969) antibiotic age.

4. The inclusion in this volume of brief summaries of surgical care of casualties overseas is logical, since much of their care in the Zone of Interior, as well as their status upon their arrival, depended upon their management overseas. Surgery in the Zone of Interior was the last step of phased wound care by the Army Medical Corps in the majority of casualties received from overseas. Some long term patients had to be transferred later to Veterans' Administration hospitals for additional care.

The evolution of fracture management in the Mediterranean theater was particularly important. It eventually came to include debridement; delayed wound closure; whole blood transfusions (instead of the large amounts of plasma previously used); and antibiotics, used with discretion and with full recognition of their limitations. Once this program was completely implemented, there was immediate and notable improvement in the status of casualties received in the Zone of Interior and in their prognosis.

5. Some of the material in this volume, such as that dealing with induction standards, limited service, and terminal examinations, is not exclusively orthopedic. Orthopedic surgery represented the heaviest load of casualties—up to 70 percent at some times and in some areas—and these considerations occupied a great deal of the time and attention of orthopedic surgeons, both administratively and clinically.

6. Overall official statistics are generally lacking in this volume. They will appear in statistical volumes presently in preparation. Here, they are replaced by small series of cases either personally collected by officers with special interest in certain conditions or prepared on special assignment.

7. There is very little followup in this volume, as would be expected, since the cutoff date for it was December 1945. Followup studies, it was decided, belong to the Veterans' Administration and other agencies.

8. There is considerable overlapping of the material in this volume, though as much as possible of it has been eliminated by the liberal use of page cross references. What remains is deliberate, unavoidable, or both, as, for instance, the multiple references to quadriceps exercises. Existing repetition does not represent careless organization.

9. The contents of this volume do not include, except incidentally, any material on hand surgery, vascular surgery, neurosurgery, and physical therapy and reconditioning. Each of these subjects is treated in a special volume.

10. Finally, this volume should be read and evaluated in the light of the realization that whatever happens to a soldier in service is the responsibility of the Medical Department, no matter when or where or in what circumstances the injury or lesion was sustained.

MATHER CLEVELAND, M.D.
ALFRED R. SHANDS, Jr., M.D.

Acknowledgments

The preparation of this volume has been a truly composite effort. Without the invaluable assistance of our confreres, who contributed both written material and oral history, we could not have fulfilled our editorial responsibilities.

In particular:

The entire amputation section and the major part of the chapter on administration were prepared by Dr. (formerly Col., MC) Leonard T. Peterson, who served in the Zone of Interior as Consultant in Orthopedic Surgery to The Surgeon General. We are grateful for his competent and generous help. He would have been a far more logical choice for editor than either of us.

Dr. (formerly Lt. Col., MC) George K. Carpenter turned over to us the voluminous reports and other material he had collected on the very active orthopedic service he headed at Halloran General Hospital, Staten Island, N.Y. He also participated in several helpful oral sessions.

Dr. (formerly Maj., MC) Joseph D. Godfrey supplied the data on internal fixation from his exhaustive followup studies, which proved once again, and conclusively, that this is not the acceptable technique of fracture management in an overseas theater.

Dr. (formerly Maj., MC) Roy R. Ciccone provided the chapter on parachute injuries from his very wide experience in this field.

Dr. (formerly Lt. Col., MC) James J. Callahan, who served as Consultant in Orthopedic Surgery in the Fourth Service Command, wrote the chapter on march fractures, provided other material, and gave us helpful advice on various subjects.

Dr. (formerly Maj., MC) Louis W. Breck, Dr. (formerly Maj., MC) Patrick C. Doran, and Dr. (formerly Maj., MC) Samuel H. Nickerson provided most of the material on training injuries.

Dr. Jack K. Wickstrom, now Chairman, Department of Orthopedic Surgery, Tulane University of Louisiana School of Medicine, New Orleans, La., furnished assistance as it was needed to the Associate Editor of this series, whose office is at Tulane. He spared her and us a great deal of correspondence and saved us considerable time.

Our thanks are due to a number of persons in the Historical Unit, U.S. Army Medical Department. The work was begun while Col. John Boyd Coates, Jr., MC, was Director of the Unit, continued during the tenures of Col. Arnold Lorentz Ahnfeldt, MC, and Col. Robert S. Anderson, MC, and was concluded under the present Director, Col. William S. Mullins, MSC. We are grateful for their concrete assistance and for their encouragement and enthusiasm.

Personnel of the General Reference and Research Branch of The Historical Unit supplied much of the material on which this volume is based. Our special thanks are due to Mrs. Esther E. Rohlader, who not only produced material as it was requested but also performed the task of tracking down missing and contradictory items.

In the Editorial Branch, Mrs. Martha R. Stephens was responsible for final editing, and Mrs. Marjorie G. Shears, the artwork and layouts.

The final copies of the manuscript were made with efficiency and speed by Miss Margaret Abbott and Mrs. M. Imogene Andrews. Mrs. Hazel G. Hine, Chief of the Administrative Branch of The Historical Unit, supervised the typing of the manuscript that went to the printer.

The editorial work was done, and the index made, by Miss Elizabeth M. McLetridge.

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Contents

Figure *Page*

Illustrations

Charts

Tables

Part I

ADMINISTRATION

CHAPTER I

Historical Note

Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

THE EVOLUTION OF ORTHOPEDIC PARTICIPATION IN WORLD WAR I

All activities, medical as well as military, during the participation of the United States in World War I[1] were based primarily on the National Defense Act of 22 June 1916 (*1*).

Initial Activities and Organization

On 14 April 1916, probably prompted by the legislation just referred to and then pending in Congress, a group of distinguished surgeons met in Chicago, Ill., and organized a Committee on Medical Preparedness (*1*). This committee represented about 70,000 physicians in five organizations; namely, the American Medical Association, the American Surgical Association, the Congress of American Physicians and Surgeons, the Clinical Congress of Surgeons of North America, and the American College of Surgeons.

On 26 April 1916, in compliance with action taken at the meeting of 14 April, the committee informed the President of the "desire and willingness" of the profession to make a comprehensive survey of the medical resources of the country and to prepare a complete inventory of them. The planned survey would cover physicians trained in the specialties of medicine, surgery, and sanitation; trained nurses and adjunct medical personnel, hospitals and buildings available for use as hospitals; facilities for transportation of the sick and wounded; and locations of available food and drug supplies.

The President referred this letter to the Secretary of War, who consulted with The Surgeon General, and steps were taken at once to implement the planned survey.

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[1] The orthopedic sections of the official history of the U.S. Army Medical Department in World War I were prepared by Col. Elliott G. Brackett, MRC, who served as Chief of the Division of Orthopedic Surgery in the Surgeon General's Office during that war. His material was derived from reports made by 18 orthopedic surgeons, one of whom, Maj. Norman T. Kirk, MC, was to serve as The Surgeon General of the Army during World War II, in the grade of Major General.

All of the material in this chapter has been obtained from the official history of the U.S. Army Medical Department in World War I (*1–6*).

On 29 August 1916, an advisory body, the Council of National Defense, was created by act of Congress (*2*). The membership, which consisted of the Secretaries of War, Navy, Labor, Commerce, Interior, and Agriculture, was assisted by an advisory commission of seven other members with special knowledge and skills in various areas. Members of the Medical Preparedness Committee had wired The Surgeon General, shortly after the Council was created, asking that there be a medical member on the advisory commission; and it was perhaps in response to their urgings that on 11 October 1916, Dr. Franklin H. Martin was appointed to it.

Dr. Martin at once established his own medical committee, with Dr. Frank F. Simpson as Secretary. Dr. Simpson also served as Secretary of the Committee of American Physicians on Medical Preparedness, and as Chief of the Medical Section, Council of National Defense. Dr. Martin's committee, officially termed the "General Medical Board," represented the civilian medical population in relation to the four administrative governmental agencies; that is, the Army, the Navy, Public Health Service, and American National Red Cross. It was through this board that the wartime activities of the medical profession were carried out.

Survey of Orthopedic Needs

World War I was to show more clearly than any previous war the need for specialists in the Medical Department of the Armed Forces, but only orthopedic surgery was to take action before the United States entered the war (*3*). At a meeting of the American Orthopedic Association in Washington, D.C., in May 1916, a preparedness committee was appointed in consideration of "possible contingencies which might arise in this country from the war in Europe," and was instructed to investigate the needs and equipment of orthopedic hospitals should they be required in a future emergency. The work of this committee on the selection and standardization of special orthopedic supplies and equipment was reported to the association at the meeting in Pittsburgh, Pa., in May 1917, a month after the United States had entered the war.

At this meeting, the association offered its services to the Government in any way possible and mentioned, as a practical activity, aid in drawing up methods of examination and treatment in orthopedic conditions likely to affect soldiers in training (*3*). When this offer was presented to The Surgeon General on 2 July 1917, he accepted it at once and asked that these directions be prepared immediately for distribution to surgeons in camps. He wished them to serve as the basis of examination and instruction in all matters "of orthopedic interest" and as a guide for the standardization of military orthopedic usage. It was specified that the subject matter include the feet and footgear.

Several members of the association were ordered at once to Washington, to aid in the preparation of these instructions.

Care of Orthopedic Casualties

Almost as soon as the United States entered the war, The Surgeon General, aware of the experiences of England, France, and Canada, recognized the need for caring for disabled soldiers who would be returned to the United States from overseas and rehabilitating them for return to their former occupations or preparing them for new occupations more suitable to their handicapped status (*3*). In April 1917, he arranged through the Military Director of the American National Red Cross for the establishment of two hospitals for the "reconstruction of disabled soldiers," one in Boston, Mass., in connection with Robert Brigham Hospital, and one in Washington, in connection with the Soldiers' Home. Both were equipped and staffed for medical and surgical care and for industrial rehabilitation.

In May 1917, the British liaison officer in Washington requested that a number of American orthopedic surgeons be sent to England, where the need for them was urgent and where also they could witness the possibilities of returning disabled men to service or training them for industrial occupations (*3*). Twenty volunteers were secured from different parts of the country, and it was arranged with British authorities that, if any of them were needed for work among U.S. soldiers on the Continent, they would be replaced by other orthopedic surgeons. Maj. Joel E. Goldthwait, MRC, who had been representing orthopedic surgery in the Surgeon General's Office, was detailed to accompany the group, to help distribute them, to study the overall orthopedic situation, and to report on these matters to The Surgeon General.

Organization in the Surgeon General's Office

Maj. Elliott G. Brackett, MRC, had continued Major Goldthwait's duties during his absence because of The Surgeon General's recognition of the importance of enrolling orthopedic personnel in the Armed Forces and preparing hospital accommodations for the wounded. On 25 July 1917, Major Brackett was formally placed in charge of "orthopedic surgery and orthopedic reconstruction" (*3*).

After Major Goldthwait's report of conditions in England and France on his return in August 1917, there could be no doubt of the need for ample provisions for the care of orthopedic casualties. The Surgeon General, therefore, set up in his office on 20 August 1917 a special Division of Orthopedic Surgery, with subdivisions for personnel; inspection and supervision; courses of instruction; camp and hospital reports; artificial limbs and apparatus; publications; and supplies (*4*). It was the function of this new division to plan for appropriate personnel both in France and in the United States, to arrange for special equipment overseas, and to provide for special care for orthopedic casualties as soon as possible after wounding. Orthopedic reconstruction was also to be a function of this division.

Later, The Surgeon General created a Department of Special Hospitals and Physical Reconstruction, which still later became the Division of Physical Reconstruction (*3*).

Major Brackett and his assistant directors were aided by an Advisory Orthopedic Board, composed chiefly of former presidents of the American Orthopedic Association and representatives of the Orthopedic Section of the American Medical Association. At the first meeting of this board, held on 2 August 1917 (before the establishment of the Division of Orthopedic Surgery in the Surgeon General's Office was formally announced), it was recommended that a letter be sent to all orthopedic surgeons requesting that all "questions of an orthopedic nature" be submitted to, and go through, the chairman of the board. Another circular letter was recommended, to secure information concerning the qualifications and availability for service of orthopedic surgeons in the United States. A followup bulletin giving information about activities of the Division of Orthopedic Surgery was also planned, to be sent at intervals to all physicians interested in orthopedic surgery (*3*). Finally, in view of the number of physicians who would be called on to do orthopedic surgery during the war, it was recommended that universities and hospitals give additional training to those who would care for orthopedic casualties.

The organization in the Surgeon General's Office which had just been described continued in that form until the fall of 1918, when, after the Armistice, the number of administrative divisions in the office was reduced from 32 to 11 (*3*). At this time, the Division of Orthopedic Surgery became a section under the Division of Surgery and so continued until 9 September 1919, when the Division of General Surgery became a section of the Hospital Division.

ORTHOPEDIC RESPONSIBILITIES

When the Division of Orthopedic Surgery in the Surgeon General's Office was announced on 20 August 1917, the "classifications * * * of the conditions to be considered orthopedic," which were practically the same as those used by the British Government, were derangements and disabilities of joints, including ankylosis; deformities and disabilities of the feet, such as hallux valgus, hallux rigidus, hammer toe, metatarsalgia, painful feet, and flat or claw foot; mal-united or un-united fractures; injuries to ligaments, muscles, and tendons; tendon transplantation or other treatment for irreparable destruction of nerves; nerve injuries complicated by fractures or stiffness of joints; and conditions requiring surgical appliances including artificial limbs (*4*).

The unsettled situation in respect to division of orthopedic and general surgical responsibility that existed in World War I is evident in the complaint of a certain Maj. John Ridlon, MC, who took the 20 August 1917 promulgation literally and interpreted it to mean that orthopedic surgeons

should care for mal-united and un-united fractures (*5*). Maj. Edward Martin, MC, thought that fractures were a responsibility of general surgeons, and the Surgeon General's Office had to settle the matter. The decision was that, if a soldier was to have the best possible care, he must not be referred automatically to one group of surgeons or the other since "the only reasonable basis of distribution is individual fitness, and this must be determined by local conditions." The basis of this decision was that, while a large number of orthopedic surgeons possessed "the greatest skill in this difficult work," some did not. Similarly, while many general surgeons showed "preeminent skill" in fracture work, many who possessed "the highest ability in certain lines of general surgery" had neither interest nor skill in fractures. No such conflicts of interest, of course, arose in World War II, when the place of orthopedic surgery as a specialty in which fractures were included had long since been established.

Preexistent disabilities and diseases, however, constituted as much of a problem in World War I as they did later in World War II (*6*) (p. 93).

PERSONNEL AND TRAINING

The original personnel for orthopedic surgery were obtained from available trained orthopedic surgeons, but it was soon evident that this group could not possibly meet the needs of the Army (*3*). Additional orthopedic surgeons, it was apparent, must be found among younger general surgeons and "the many young practitioners who had already obtained acceptable training along surgical lines." It was equally apparent that special instruction in orthopedic principles would be necessary to train these younger men to serve under qualified orthopedic surgeons.

It was the personnel policy of the Orthopedic Division, Surgeon General's Office, to depend entirely for the first contact with an orthopedic surgeon on his personal application or on the recommendation of a civilian physician or a physician already in service (*3*). All such candidates were immediately "reserved to orthopedic service" if they were not yet commissioned or to the orthopedic service if they were already in service and not yet "reserved" to other sources. An attempt was made in each instance to verify all statements concerning experience and qualifications before deciding on the candidates' desirability and availability. Once they were inducted, they were assigned to various courses of instruction in orthopedic surgery to qualify them in the military and other aspects of their future work before they assumed camp responsibilities.

Early in September 1917, arrangements were made with Harvard University to establish courses of instruction in orthopedic surgery, and a syllabus for them was prepared with the aid of the Advisory Board (*3*). Another course was set up in Philadelphia, Pa., in the middle of October. Early in November 1917, with the experience gained in these preliminary courses, the Advisory Commission met with the instructors who had con-

ducted them, and a standardized schedule was decided on which was used in all subsequent courses. By the end of the war, these courses had been given in Chicago, New York, N.Y., Oklahoma City, Okla., and Los Angeles, Calif., at Camp Greenleaf, Ga., and at the Army Medical School, Washington, D.C. In all, 691 officers were trained in this manner. In the light of present-day standards of orthopedic training, these courses were, of course, superficial and inadequate, but the officers trained in them performed well in service and formed the nucleus of the orthopedic surgeons in civilian practice after World War I.

Special phases of orthopedic administrative policies and professional care in World War I will be found elsewhere in this volume under appropriate headings.

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CHAPTER II

General Administrative Considerations in the Zone of Interior

Leonard T. Peterson, M.D., Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

GENERAL CONSIDERATIONS OF ADMINISTRATION

In World War I, the responsibilities of orthopedic surgeons and general surgeons in the management of orthopedic injuries were not entirely clear. In World War II, just as in civilian practice, both injuries and other lesions of the bones, joints, and related skeletal structures were the acknowledged province of orthopedic surgery. No other specialty carried so heavy a load. In the European Theater of Operations, U.S. Army, orthopedic casualties comprised approximately two-thirds of the 381,350 injured and wounded in action (*1*). As a result, orthopedic surgeons, because their number was limited, were frequently and of necessity assisted by medical officers with little or no training in this specialty, or by personnel trained in other specialties. Nonorthopedic personnel often had to carry the entire orthopedic responsibility. On the other hand, it was exceptional indeed for orthopedic surgeons to care for any but orthopedic casualties.

Orthopedic surgery in World War II differed from civilian orthopedic surgery in certain important respects:

1. High explosives, high-velocity bullets, mines, bombs, and boobytraps all contributed to extensive wounds of both soft tissues and bones, of types practically never seen in civilian practice.

2. The highly mechanized vehicular and other equipment in general use in the Army was responsible for many injuries similar to, but of greater frequency, and often of greater severity than, those observed in civilian practice.

3. Basic training, which was taxing and demanding, resulted in large numbers of injuries (p. 227). Numerous injuries, some of them of a highly special kind, also occurred during paratrooper training (p. 775).

4. Severe and extensive as many of these injuries were, they occurred, nonetheless, in a selected cross section of robust, vigorous young men, in the best decades of their lives.

5. To these inherently favorable circumstances were added others:

a. First aid was practically always prompt and was almost invariably efficient.

b. As the war progressed, resuscitation became increasingly competent. Blood and plasma were available in whatever quantities were needed (*2*), and the realization grew that initial wound surgery was an inherent phase of resuscitation and that antibiotic therapy, even after penicillin became available, was no substitute for it (*3*).

c. The wise application of these measures resulted in an enormous salvage of limb as well as of life. The proportion of casualties returned to the United States was far larger than in World War I, as well as the proportion with limbs in situ; and the condition of these men, generally speaking, was far better than that of the casualties returned in the First World War.

In addition to the revision (reamputation) of amputation stumps and the rehabilitation of amputees, the major orthopedic problems of Zone of Interior hospitals concerned compound fractures and their complications, which included vascular injuries, infection, malunion, nonunion, and the loss of bony substance.

Vascular complications (*4*) were seldom seen on orthopedic sections of Zone of Interior hospitals; they required immediate surgery, most often amputation, in forward hospitals overseas. Nerve injuries (*5, 6*) coexisted with bone injuries in 15 percent or more of all cases and required close cooperation between neurosurgeons and orthopedic surgeons for the best results. Close cooperation between orthopedic and plastic surgeons was also necessary in the many cases in which extensive soft-tissue damage required plastic repair before major orthopedic surgery could be undertaken. Often, many months elapsed before the orthopedic phase of a given injury could be begun; it was promptly learned that attempts to expedite recovery by undertaking bone surgery before complete wound healing was an almost certain means of prolonging it.

In general terms, the management of combat casualties in the Zone of Interior included (*7*):

1. Elimination of whatever infection existed.
2. Improvement of the local blood supply and restoration of the vasomotor tone of the part.
3. Requiring the patient to use the injured extremity before as well as after operation. The best results were usually secured if he was required to perform tasks just beyond the limit of his ability.
4. Reconstructive surgery, carefully planned for the needs of the particular patient.
5. An attitude of insistent optimism about the ultimate result. The keynote of success was flexibility in planning and inflexibility in implementation. It was essential for both patient and surgeon to avoid the risk of psychologic defeat and to be unwilling to accept less than the maximum that could be accomplished. Very difficult to handle were the patients who

had been told, or who thought they had been told, that they would need no further surgery and who sometimes had to be informed that the most difficult operation of all lay ahead of them. Reconstructive surgery was another ordeal, but it was, of course, free from many risks which attended it in World War I, thanks to the adjunct measures available in World War II.

The orthopedic surgeons in Zone of Interior hospitals had a problem common to all military surgeons in all wars: The principal function of the Medical Corps was—as it still is—to keep soldiers able-bodied and fit for military duty. In civilian life, most patients with orthopedic conditions have illnesses or injuries that clear up after brief periods of general postoperative care, rest, and physical therapy. Relatively few require the extended treatment and prolonged hospitalization that many combat casualties of World War II required. In civilian practice, moreover, the decision to perform elective surgery is relatively simple. In military orthopedic practice, it was often hard to make. Indeed, the implementation of the policies and practices decided upon often was far simpler than the making of the basic decisions.

ORGANIZATION OF THE SURGEON GENERAL'S OFFICE

The Professional Service Division that existed in the Surgeon General's Office before World War II can perhaps be regarded as the predecessor of the consultant system that developed during the war (*8, 9*). The scope of this division, however, was limited, and its functions were chiefly administrative, in contrast to the important clinical and other activities engaged in by the consultants of World War II. Among the seven subdivisions of this prewar agency was a subdivision of Medicine and Surgery, a combination of major specialties so clearly impractical that further subdivision was inevitable.

The appointment of Col. (later Brig. Gen.) Fred W. Rankin, MC, on 1 March 1942 as Chief Consultant in Surgery to The Surgeon General was followed shortly afterward by the establishment of a separate Surgery Division, with orthopedic surgery as one of its subdivisions. Other reorganizations followed, and in August 1944, the Surgery Division underwent a final change, becoming the Surgical Consultants Division, with orthopedic surgery continuing as one of its components. At the same time, the Surgery Division was separated completely from the Professional Service Division and became, instead, an independent agency directly responsible to The Surgeon General.

On 8 September 1943, Col. Leonard T. Peterson, MC, was assigned as Consultant in Orthopedic Surgery to what was then termed the "Surgical Division, Professional Service, Surgeon General's Office," although the Orthopedic Branch of the division was not officially established until 17 December 1943 (*10*). At this time, all physical therapy activities in the

office became the responsibility of the Orthopedic Surgery Branch. In July 1944, all such activities in Army hospitals were also placed under orthopedic surgery (*11*).

Physical therapy remained the responsibility of orthopedic surgery until April 1946, when it became a separate branch of the Physical Medicine Consultants Division (formerly the Reconditioning Consultants Division), Surgeon General's Office (*12*). Control of the physical therapy section in named general hospitals was transferred from the Orthopedic Section to the Physical Medicine Service in November 1946 (*13*).

THE CONSULTANT SYSTEM

The Surgeon General's Office

When Colonel Peterson reported to the Surgical Consultants (then Surgical) Division, of the Surgeon General's Office, in September 1943, he noted in his official diary that he was given a friendly reception but no orientation, nor was he assigned any specific duties, probably, he reasoned, because his position as orthopedic consultant was newly created. His reasoning was correct. His dilemma simply duplicated that which had existed originally for his superior officer, Colonel Rankin, when he reported as Chief Consultant in Surgery to the Surgeon General's Office in March 1942.

In the annual report of Professional Service, Surgeon General's Office, for 30 June 1942 (*14*), it was stated that the functions of a senior consultant were to keep abreast of advances in civil and military medicine, to determine policies concerning various aspects of surgical practice, to prepare directives concerned with these matters, to make frequent inspection trips to station and other hospitals and to service command headquarters, and to evaluate the suitability of drugs and surgical equipment for Army medical installations.

The lack of a more precise definition of functions did not long handicap a person of Colonel Rankin's tremendous energy and dedication. No matter how they were originally envisaged, under his direction, they were soon widely expanded. In the report of the Surgery Division, Surgeon General's Office, for 1943–44 (*15*), the statement of functions became considerably more specific. Now consultant personnel were expected to "* * * exercise general supervision of surgical care throughout the Army, afford consultation and advice to all departments of the Surgeon General's Office on matters pertaining to surgery, and to assist in the identification and proper allocation of qualified commissioned surgical specialists."

In addition to the major policies thus stated, the functions of consultants in the Surgeon General's Office soon came to include supervision of programs of medical education and training; dissemination of information, including the preparation of circular letters and other directives; organiza-

tion of conferences; and maintenance of liaison with personnel of the National Research Council, medical schools, and other appropriate organizations and agencies, as well as with the civilian profession.

General Rankin, at a conference of service command consultants in October 1943 (*16*), stressed the responsibility of consultants for advising and assisting service command surgeons in determining the quality of surgery performed in their commands; in evaluating surgical standards within them; in evaluating surgical personnel in the commands in respect to (1) character and capabilities and (2) efficient distribution and utilization; and in advising the command surgeon on special surgical problems. It is interesting to recollect that the evaluation and allocation of professional personnel, not even mentioned in the 1942 statement of consultant functions, were to become perhaps the most useful and significant of all duties performed by consultants in all specialties. In July 1943, Lt. Col. (later Col.) B. Noland Carter, MC, wrote to all service command consultants to stress the importance of evaluation and assignment of personnel, including recommendations for their removal if they were not considered fitted for their assignments (*17*). All consultants were repeatedly reminded that the report of errors and deficiencies in all areas, with recommendations for their correction, constituted important phases of consultants' responsibilities.

Most of the functions described had become well-established responsibilities of consultants by the time Colonel Peterson came to the Surgical Division, of the Surgeon General's Office, and he soon found that his duties were similar to those of the Chief Consultant in Surgery as they concerned the specialty of orthopedic surgery.[1]

There were many ramifications of these formal functions. For instance, one time-consuming occupation was a review of, and reply to, all letters received by The Surgeon General or by other agencies of the Government relating to orthopedic matters. All of these letters were referred to the Consultant in Orthopedic Surgery. It was necessary, as a matter of public relations, to answer them all courteously and as specifically as possible, but when they were long, involved, and clearly from cranks, it was the part of

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[1] The consultant system in the U.S. Army Medical Department in World War II was conceived of, and developed after, the United States entered the war in December 1941. It is interesting, therefore, to read Sir Alfred Keogh's concept of consultants in the British Army, written in 1916, a year before the United States entered World War I (*18*):

"In war, the regular officers of the Medical Corps are compelled by circumstances to turn their attention and their energies to administrative matters, leaving to specially selected experts the technical work which the care of the sick and wounded involves. * * * Hence the appointment of Consulting Surgeons, by whom all subsequent surgical developments can be determined. They set the scope and the standard of practical work and scientific investigation. The Administration relies entirely upon them for the fixing of surgical policy. The responsibilities of these officers are great; their efficiency is proportional to their own appreciation of their powers. They determine whether the means at the disposal of the hospital surgeons are adequate or not. They supervise the operations and approve the operators, so that upon them depends whether or not all that is best in British surgery is available for the soldier. No official can afford to treat lightly representations made by them, and no commander would hesitate to accept their carefully considered verdict on any question submitted to them. These are great powers, but they are no greater than the importance of the subject requires. It is therefore through the consultants, and through them alone, that the maximum of surgical efficiency can be attained."

wisdom to be as definitive as possible in the original communication to avoid involvement in a prolonged and futile correspondence.

Service Commands

Appointment of consultants in orthopedic surgery in certain service commands was a logical outgrowth of the workload in them, early in the war from training injuries (p. 227), later from combat injuries, and throughout the war from vehicular injuries. During 1943 and 1944, for instance, the Fourth Service Command, which included North and South Carolina, Georgia, Florida, Tennessee, Mississippi, and Alabama, had some 2 million troops in training and was served by 130 station and 11 general hospitals.

Service command consultants were appointed between May 1943 and May 1945 as follows:

Fourth Service Command, Lt. Col. (later Col.) Mather Cleveland, MC, September 1943. In June 1944, after Colonel Cleveland had been ordered overseas, he was succeeded by Maj. (later Lt. Col.) James J. Callahan, MC, who served until the end of the war.

Fifth Service Command, Maj. (later Lt. Col.) Robert L. Preston, MC, May 1943.

Sixth Service Command, Maj. (later Lt. Col.) Ralph Soto-Hall, MC, June 1944.

Seventh Service Command, Lt. Col. Vernon L. Hart, MC, May 1945.

Eighth Service Command, Lt. Col. (later Col.) Thomas L. Waring, MC, October 1943.

Ninth Service Command, Maj. (later Lt. Col.) John J. Loutzenheiser, MC, December 1943.

Consultants in orthopedic surgery never were appointed for the First, Second, and Third Service Commands. The Consultant in Surgery for the Second Service Command, Col. Robert H. Kennedy, MC, was experienced in the surgery of trauma and served all orthopedic requirements admirably. In the other two commands, orthopedic supervision was also exercised by the Command Consultants in Surgery.[2]

Armies are constructed on rank, and their personnel usually are thoroughly rank-conscious. This was as true in the Medical Corps in World War II as in any other branch of service. The feeling had certain very practical implications. It was natural that service command consultants in orthopedic surgery, like all other consultants, should find themselves greatly handicapped on their tours of inspection and in other contacts if they were outranked—as they frequently were—by the commanding officers and others in the hospital installations which they were called upon to inspect and evaluate. The situation, which sometimes was highly embarrassing, arose because personnel allotments for service command headquarters carried no specific assignments or ranks for consultants.

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[2] The activities of Col. Alfred R. Shands, Jr., MC, Senior Consultant in Orthopedic Surgery to the Air Surgeon, are described elsewhere (p. 78).

Civilian Consultants in Orthopedic Surgery to the Secretary of War

The orthopedic surgeons who served as civilian Consultants in Orthopedic Surgery to the Secretary of War were all members of the American Orthopaedic Association and the American Academy of Orthopaedic Surgeons. Several were members of the Subcommittee on Orthopedic Surgery, Committee on Surgery, Division of Medical Sciences, National Research Council. One had an important industrial position and all the others had teaching appointments. They were:

Dr. LeRoy C. Abbott, Professor of Orthopedic Surgery, University of California, San Francisco, Calif.

Dr. George E. Bennett, Professor of Orthopedic Surgery, Johns Hopkins University School of Medicine, Baltimore, Md.

Dr. Harold R. Conn, Surgical Director, Goodyear Tire & Rubber Co., Akron, Ohio.

Dr. J. Albert Key, Professor of Orthopedic Surgery, Washington University School of Medicine, St. Louis, Mo.

Dr. Paul B. Magnuson, Professor of Orthopedic Surgery, Northwestern University Medical School, Evanston, Ill.

Dr. Philip D. Wilson, Clinical Professor of Orthopedic Surgery, Columbia University College of Physicians and Surgeons, New York, N.Y.

The visits of these consultants to the amputation centers in May 1944 and October 1945 are reported in the section on amputations (p. 902).

Temporary Consultants in Orthopedic Surgery to the Secretary of War

In December 1943, at the request of The Surgeon General, 13 experienced orthopedic surgeons were appointed as temporary Consultants in Orthopedic Surgery to the Secretary of War, with the mission of inspecting orthopedic services in Army hospitals in the various service commands and reporting their observations and recommendations to him (*19*). Their qualifications were essentially the same as those of the consultants just listed. Their assignments were:

Service Command	*Consultants*
First	Dr. Frank R. Ober, Boston, Mass.
Second	Dr. William W. Plummer, Buffalo, N.Y.
Third	Dr. Guy W. Leadbetter, Washington, D.C.
Fourth	Dr. H. Earle Conwell, Birmingham, Ala.
	Dr. Oscar L. Miller, Charlotte, N.C.
Fifth	Dr. Harold R. Conn, Akron, Ohio.
Sixth	Dr. Carl E. Badgley, Ann Arbor, Mich.
Seventh	Dr. Robert D. Schrock, Omaha, Nebr.
	Dr. Frank D. Dickson, Kansas City, Mo.
Eighth	Dr. Guy A. Caldwell, New Orleans, La.
	Dr. Earl D. McBride, Oklahoma City, Okla.
Ninth	Dr. LeRoy C. Abbott, San Francisco, Calif.
	Dr. John C. Wilson, Los Angeles, Calif.

During December 1943 and January 1944, each of these consultants visited six or more station and general hospitals in the service command to which he had been appointed. Their observations and recommendations were reported to The Surgeon General at a meeting of the American Academy of Orthopaedic Surgeons in Chicago in January 1944 and were summarized by Dr. Caldwell for the group at an evening session of the academy as follows:

It was the consensus of the group that the standards and practices of orthopedic surgery in the Army were excellent and that facilities and equipment were adequate. The policy of transferring to general hospitals all patients with injuries likely to be difficult and to require prolonged treatment was commended. A number of patients with compound fractures complicated by nerve injuries were observed in some general hospitals that were not neurosurgical centers. It was recommended that all such patients be transferred to appropriate centers without delay, to implement the current policy of performing nerve suture as soon as possible after injury (*5, 6*).

Specific criticisms and recommendations were as follows:

1. A tendency was observed to rely on surgery, particularly open reduction and internal fixation of fractures, in numerous cases in which more conservative treatment might better have been used.

2. At any of the hospitals visited, there did not seem to be a sufficient inclination to treat fractures by traction. The younger orthopedic surgeons, in fact, did not seem to have had sufficient instruction in the use of this technique. It was recommended that patients with fractures of the femoral shaft evacuated from overseas in plaster should be placed at once in suspension traction rather than in another cast, to prevent or correct deformity and to permit muscle reeducation and knee motion.

3. In general, there was a tendency toward too prolonged immobilization of joints, particularly the knee, the elbow, and the interphalangeal and metacarpal phalangeal joints. Mobilization of these joints, once they had become fixed, was extremely difficult.

4. Chronic indolent wounds and wounds with dense, heavy scars should be excised. Chronic sinuses associated with sequestra or foreign bodies should be explored.

5. In bone grafting for nonunion following bone infection, it was recommended that the graft be removed from the donor site and that the wound be closed and dressed before the graft bed was prepared, to avoid cross infection.

6. The position of fractures of the vertebral bodies could be improved by instituting additional hyperextension after arrival of the casualties at general hospitals, even though several weeks had elapsed since injury.

7. Complaints referable to the back and the foot furnished the chief problems of disposition. Not enough clinical study was devoted to differential diagnosis in these cases. Careful, exhaustive investigation was required before any surgery on the knee joint and before surgery for disabilities of the knee, foot, shoulder, and other joints, which were EPTI (existing prior to induction). It was the consensus of the consultants that few men would be salvaged for military service by such operations.

8. Patients who had undergone knee surgery did not seem to understand the technique of quadriceps exercises, and many times their surgeons did not seem themselves to have had adequate instruction in such exercises. Muscle tone, contour, and strength had to be restored to the quadriceps muscle before men were allowed to walk, and no soldier was to be returned to duty until the musculature of the thigh was normal.

One medical officer or one physiotherapist should be able to teach at least six patients at a time how to perform quadriceps exercises satisfactorily.

9. Otherwise, the keen interest shown in physical therapy and reconditioning was commendable, and it was recommended that these programs be developed further and used more widely.

PERSONNEL

General Considerations

Although the expansion of orthopedic surgery was rapid between the two World Wars, when the United States entered World War II, it was evident almost immediately that the increase had not kept pace with the demand and that there was a relative as well as an absolute shortage of well-trained orthopedic surgeons, a shortage which continued until the end of the war.

The requirements of tables of organization for orthopedic surgeons, had they been met, would have taken into service all physically fit orthopedic surgeons in the country under 45 years of age. This was clearly impractical, and the demand was met usually by utilizing medical officers with general surgical training, often supplemented by special Army training in orthopedic surgery (p. 21), in positions in which it would have been advantageous to have had trained orthopedic surgeons. Many of these officers performed satisfactorily, and some of them in an exemplary manner. Generally speaking, however, the scarcity of trained orthopedic surgeons placed a considerable extra burden on those specialists who had to direct and supervise large services with the aid of relatively inexperienced officers who sometimes had little interest in orthopedic surgery. On the other hand, as happened in other specialties, many officers who served in these positions during the war were attracted to orthopedic surgery, underwent formal training after the war, and eventually became certified by the American Board of Orthopaedic Surgery, Inc.

Some orthopedic surgeons who entered the Army had just finished their residencies, and while they were technically well trained, they were often immature in their judgments and could not be placed in positions of responsibility until they had had more experience. In particular, many of these young surgeons failed to realize, at least early in their service, that, while the hospitalized soldier often presented disabilities similar to those seen in civilian practice, the degree of rehabilitation that might have been accepted in civilian practice was not satisfactory in military practice because a soldier who is not completely able-bodied is seldom of value to an army.

General surgeons with little or no traumatic or orthopedic experience were never placed at the head of orthopedic services in general hospitals, but were assigned, as a rule, to station hospitals in which permissible surgery was strictly limited by official directives.

The problem of retaining skilled personnel in their assignments increased as the war progressed, and there were inroads on the orthopedic services of general hospitals and larger station hospitals in the Zone of Interior to staff newly organized hospitals going overseas. Surgeons of affiliated units were sometimes withdrawn for other units after these hospitals had completed their military indoctrination and were moved to ports of embarkation.

Classification

Classification (MOS).—The MOS (military occupational specialty) classification for medical officers, for which the orthopedic surgery rating was 3153, became operative in the Medical Department in the fall of 1943 (*20*). Its subclassifications were as follows:

Group A included officers with civilian or military backgrounds of recognized and outstanding ability in a given specialty. In this group were professors and associate professors and heads of departments in large teaching centers, as well as medical officers who could function within their specialty without professional supervision.

Group B included officers with superior training and demonstrated ability. The classification implied a probable training period of 4 years (1 year of internship and 3 of residency or fellowship) devoted to a given specialty in a recognized teaching center. Also included were medical officers with mature experience and demonstrated ability who could function within their specialty without supervision, even though they had not had the formal training just specified.

Board-certified orthopedic surgeons had ratings of A or B, though lack of certification did not necessarily deprive surgeons of these ratings. Members of both A and B groups served as consultants or were in charge of orthopedic services in general or station hospitals.

Group C included officers who had recently completed periods of training in their specialties, consisting of 1 year as interns and 2 to 3 years as residents. It also included officers with shorter periods of training, but with backgrounds of mature experience. Sometimes, because of shortages of A and B personnel, group C officers had to be put in charge of orthopedic services in station or even general hospitals.

Group D included officers who had recently completed periods of special training, including 1 year of internship and 1 year of residency in a specialty; officers who had had minimal or no training periods "but with a minor proportion of practice devoted to a specialty such as general practitioners, giving particular attention to the specialty for a period of at least three years"; and officers who had demonstrated some ability in a specialty. Officers in this group, as well as officers in group C, most often served as assistants or ward officers. As the orthopedic services increased in size, there was a great need for ward officers, and in 1945, moderate shortages occurred in both C and D categories.

The completed MOS classification, as just noted, became available late in 1943. The need for classification of orthopedic surgeons on the basis of their training, experience, and ability was evident much earlier. It was discussed in considerable detail at the conference of service command consultants in October 1943 (*16*). Classification practices up to this time had not been satisfactory, partly because of a lack of communication be-

tween the interested parties: The classification records in the Surgeon General's Office (Form 178–2) apparently were not available to service command consultants, and the recommendations of the consultants, based in large measure upon their personal observations, were not being followed. Improvements in both respects had recently been effected.

At this time, with few exceptions, orthopedic services in all named general hospitals in the Zone of Interior, as well as in some regional hospitals, were headed by Board-certified medical officers. If the service was unusually heavy, two Board diplomates were sometimes assigned to it.

1943 (Darrach) classification.—At the request of General Rankin, an illuminating study of personnel was carried out in August 1943 by Dr. William Darrach, Professor of Surgery at the Columbia University College of Physicians and Surgeons, on the qualifications and assignments of Army orthopedic personnel (*21*). Dr. Darrach first met with personnel of the Classification Branch, Military Division, Personnel Service, and was later assisted by Dr. Fremont A. Chandler of Chicago, who, because of his 9-year service on the American Board of Orthopaedic Surgery, Inc., had a wide knowledge of orthopedic surgeons in the United States.

About 10 percent of the officers whose qualifications were examined were known personally to Dr. Darrach or Dr. Chandler. The others were rated on their paper qualifications. It was very useful, in evaluating the individual officer's technical ability, to know the quality of the training he had received. An estimate of his present performance would have been of even more value, and it was hoped that consultants would be appointed who would be useful in this respect.[3]

In all, 907 medical officers with orthopedic assignments were evaluated and rated in 176 hospitals, including 43 named general hospitals, 74 numbered general hospitals, and 58 station hospitals of a thousand beds or more. Dr. Darrach and Dr. Chandler rated each officer separately from 1 to 4. Then, they rechecked those in the upper categories, so that the ratings in these groups represented their combined opinion. In the lower categories, an officer was checked by both examiners only when their ratings did not agree.

Of the 907 medical orthopedic officers evaluated, three were rated in group 1; 15 in group 2; 59 in group 2–3; 147 in group 3–2; 151 in group 3; 118 in group 3–4; 105 in group 4–3; and 309 in group 4. At the best, these classifications meant that, of 907 medical officers with a classification of S (orth), only 375, many of whom had already gone overseas, were rated group 3 or better, and were really well trained in orthopedic surgery. The 532 officers classified below 3–4 were considered qualified to be only surgical assistants or ward officers. Many had received the orthopedic rating of 4 simply because they had taken a 30-day course in an Army hospital in orthopedic surgery or surgery of the extremities.

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[3] Colonel Peterson was appointed Consultant in Orthopedic Surgery, Surgeon General's Office, the following month (September 1943) (p. 11). One of his duties was the continuing study of the classification of orthopedic personnel and making recommendations for updating their MOS ratings.

Dr. Darrach and Dr. Chandler next concerned themselves with the conditions being handled on orthopedic services, which fell into three groups:

1. The usual run of orthopedic conditions such as congenital and acquired deformities (talipes, scoliosis, postinfantile deformities); chronic infections of bones and joints, especially tuberculosis, which was no longer common; and "weak" backs and feet.
2. Traumatic conditions also encountered in civilian life, such as simple and compound fractures, dislocations, joint derangements (especially of the knee and spine), and extremity wounds without fractures.
3. War wounds.

When the training and experience of the 907 medical officers evaluated were examined in the light of this distribution of patients, wide variances were found. In such specialized hospitals as the New York Orthopaedic Hospital, the Hospital for Special Surgery (formerly the Hospital for Ruptured and Crippled), and all Shriners' Hospitals, the majority of patients fell into group 1. Many other orthopedic surgeons did chiefly fracture work. The number of officers who had had any experience with combat wounds was very limited, and in situations in which the workload was chiefly traumatic, those whose peacetime experience had been chiefly with the conditions in group 1, although they adapted rapidly, were not initially very useful.[4]

The final Darrach-Chandler conclusion was that, of the 907 medical officers whose records were examined, 17 were qualified to be consultants in orthopedic surgery and 77 were qualified to be chiefs of large orthopedic sections. Many of those classified as group 3–2 were young men who had just finished training and who should work under supervision for several months before being given more responsible assignments; it was thought that 151 of these might take on such assignments after a longer experience.

Specialization and Assignment

Early in the war, the Personnel Division in the Surgeon General's Office and other agencies perpetuated the prewar philosophy that the Army was no place for specialization. It is ironic that, before the war ended, there were not enough specialists in various fields, including orthopedic surgery,

[4] While Dr. Darrach admitted to only a limited knowledge of current military conditions, he had had a considerable experience, both at the front and in base hospitals, in 1917–18, in both the British and the American Expeditionary Forces. In the light of this World War I experience, he emphatically questioned the assumption that all wounds of the extremities should be assigned to orthopedic sections. If the World War II experience (it was then August 1943) should correspond with the World War I experience, in his opinion, 80 percent of all wounds would involve the extremities (30 percent compound fractures and 50 percent wounds of the soft parts without bone, nerve, or vascular injuries). The 907 surgeons classified—many of them generously—as orthopedic surgeons were simply too few to care for such numbers of wounded, especially since so many of them had had so little experience with trauma. For the future, trauma would occupy most of the surgeons' attention. In the light of these facts, Dr. Darrach strongly recommended that patients assigned to orthopedic sections be limited to those with group 1 conditions, amputations, and knee derangements, and that simple and compound fractures and other extremity wounds be referred to general surgical sections. This advice was not followed.

to supply the demands for them. Indeed, the proper assignment of specialists and their correct utilization eventually became the most brilliant of World War II medical achievements.

Kubie's study on specialization in the Armed Forces, although not published until 1944, had been carried out several years earlier (*22*). His figures, derived from the "Directory of Specialists Holding Certification by American Boards" (presumably the 1942 edition) and the "American Medical Directory," showed that, of some 180,000 physicians in the United States, 1,800 were then on active duty in the Armed Forces. Of 10,118 certified by the various boards, 77 were from the Army and 45 from the Navy. The majority of these 122 officers were certified in ophthalmology or otolaryngology. Specifically, according to Kubie's study, the American Board of Orthopaedic Surgery, Inc., which had been founded in 1934, had a total of 660 diplomates, not one of whom was then in service, while of the 110 members of the American Orthopaedic Association, only one was in service.[5]

These figures are somewhat misleading. For a number of years before the war, Walter Reed General Hospital, Washington, D.C., had a 4-year training course in surgery, with rotation through the various surgical specialties, and many military surgeons were competent specialists in their fields, though they were not certified. Frankly, many of them then saw no advantage in certification. Those with authority over Army medical personnel believed that a military surgeon should be able to play many roles, including duty in the field, administration, general practice, and medicine or surgery. Many Regular Army medical officers were assigned necessarily to administrative duties, but, before the war, a group of well-trained specialists in various fields were rotated through general hospitals as chiefs of service.

The original concept of specialization in the military service was responsible for some delays in the appropriate use of specialized personnel. In October 1942, Col. (later Maj. Gen.) George F. Lull, MC, wrote to Dr. Kubie: "When a young doctor enters the Medical Corps of the Army or Navy, there are certain things that he should make up his mind that he must sacrifice if he is to be successful. One of these is any high degree of medical specialization. He must become a specialist in military medicine instead. * * *"

Earlier, Colonel Lull had taken the same attitude in replying to a complaint that dermatologists were not practicing their specialty (*24*). And at about this time, Maj. (later Col.) Sam F. Seeley, MC, Chief, Office of Procurement and Assignment Service, War Manpower Commission, Office of Emergency Management, wrote the same complainant that, "Many men who anticipate that their experience will make specialists out of general practitioners are going to have to be satisfied with having been made better

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[5] Kubie does not mention which editions of the directories he used, which makes it difficult to check his figures. According to the Secretary of the American Board of Orthopaedic Surgery, Inc., Dr. William A. Larmon, 507 orthopedic surgeons had been certified through 1938 and 584 through 1939 (*23*). By 1942, the number of diplomates had reached 685. The only member of the American Orthopaedic Association in service at the time of Kubie's study was Col. (later Maj. Gen., The Surgeon General of the Army) Norman T. Kirk, MC. Col. Jesse I. Sloat, MC, was elected to membership in this association in 1942.

practitioners if now engaged as specialists. We must win this war and then enjoy our highly developed specialization."

The comment is justified that a considerable amount of specialization in the Medical Corps, including orthopedic specialization, helped to win the war.

The annual report of the Surgery Division, Surgeon General's Office, for 1943–44 (*15*) showed that 227 officers certified in various specialties were then in the Army, including 27 in the Army Air Forces. Of these, 98 percent were doing work in line with their professional qualifications.

In April 1945, General Rankin made a second analysis of surgical specialists in the Army and found that, of 922 officers certified in various specialties and on duty in the Zone of Interior, all but 37, 4 percent, were properly assigned and were carrying out duties in their own special fields (*25*). The 37 who were not doing clinical surgery were serving as consultants in the Surgeon General's Office or in the service commands. Of the 150 certified orthopedic surgeons then in service, 143 were working in that specialty.

The Surgeon General assigned personnel to all medical installations in the Zone of Interior and staffed all hospitals going overseas, but, though he maintained control of all hospital staffs in the Zone of Interior, he had no jurisdiction over the staffs of overseas hospitals. The assignment of personnel to specific duties was the function of service commands and subordinate units.

Once the Orthopedic Branch was set up in the Surgical Consultants Division, Surgeon General's Office, the Consultant in Orthopedic Surgery recommended the initial assignment of orthopedic surgeons as they entered service and the transfer of personnel for various reasons, including his decision that they were unsuited, by training, experience, or personality, for the positions they were occupying. The Personnel Division, Surgeon General's Office, usually accepted his recommendations.

Much useful information concerning the qualifications of orthopedic personnel was obtained from the American Academy of Orthopaedic Surgeons, the American Orthopaedic Association, and the American Board of Orthopaedic Surgery, Inc. It is ironical—and unfortunately typical—that Colonel Peterson did not have direct access to the report of the Kenner Board, which in 1943 studied the overall problems of personnel staffing in the Army (*26*).

A useful change in the Surgeon General's Office occurred on 1 October 1943, when the Personnel Planning and Placement Branch, to which was later added the former Records Branch, was set up in the Military Personnel Division (*27*). This new Records and Statistics Branch kept individual records of all Medical Corps officers in the United States according to their specialties, together with official requirements in these categories. Among its other advantages, the new system permitted The Surgeon General to demonstrate to Headquarters, ASF (Army Service Forces), and the War

Department General Staff that, as had been pointed out at the service commands consultants conference in October 1943 (*16*), and on other occasions, the AAF (Army Air Forces) had a larger share of medical officers in relation to its workload than the Army Service Forces. As a result, several hundred medical officers, including orthopedic surgeons, were transferred to the Army Service Forces.

Colonel Peterson recommended the initial assignment of orthopedic surgeons returning from overseas, but his recommendation could be changed within the service command by the surgeon of the command in which the assignment was located.

At the consultants conference in October 1943 (*16*), General Kirk indicated his desire that the best qualified personnel in all specialties should be transferred from station hospitals to general hospitals, where, because of the nature of the workload, the need for them was greater.

Other considerations besides training and experience entered into recommendations for assignment and transfer. The surgeon's capacity for work had to be taken into account. Maj. (later Lt. Col.) George K. Carpenter, MC, mentioned ruefully the orthopedic surgeon from a general hospital who found it impossible to take proper care of 300 patients with only four assistants. At that moment, at Major Carpenter's own hospital (Halloran General Hospital, Staten Island, N.Y.), three orthopedic officers were taking care of 600 patients. Colonel Peterson mentioned in one entry in his official diary the workload at Ashford General Hospital, White Sulphur Springs, W. Va., where Maj. (later Lt. Col.) Robert P. Kelly, Jr., MC, was conducting a service on which the census had risen to 700, though he had one less assistant than he had just after the service was organized, when the census was much smaller.

Personality problems, of course, existed in the Army Medical Corps, and changes of assignment sometimes had to be recommended for this reason, though the officers in question might be well qualified professionally for their responsibilities.

Frequent changes of assignment because of promotions, the needs of hospitals going overseas, and other reasons often made it difficult to maintain efficient orthopedic services. Orthopedic personnel had no control over nursing assignments, but frequent changes in them compounded their problems.

Chiropodists

Army Regulations No. 615–26, dated September 1942, gave chiropodists (podiatrists) the occupational code No. 0–52.010, specification serial No. 422, and outlined their qualifications and functions as follows (*28*):

1. They must have completed the course of study recommended by the Council on Education of the National Association of Chiropodists and must hold a degree of

Doctor of Surgical Chiropody (D.S.C.) from an accredited school of chiropody or podiatry.

2. Their functions were:

a. To diagnose and treat minor ailments of the human foot.

b. To remove corns and bunions "by medical, mechanical or surgical means and massages in connection herewith, except amputations of foot or toe or the use of anaesthetics or drugs other than local anaesthetics or local antiseptics."

c. To prescribe correct footgear.

Chiropodists worked under the supervision of orthopedic surgeons. Their work was limited to clinics and, in spite of the provision for this function, they did not remove bunions or perform other surgery beyond the removal of corns, calluses, and plantar warts. They also strapped arches and ankles to relieve foot strain; cut felt pads to be inserted into shoes or strapped under arches; and, in some hospitals, made arch supports. They worked very effectively carrying out these and other specified duties. They were particularly useful in large orthopedic clinics in which professional help was limited or to which patients who should have been cared for in dispensaries had been referred for treatment.

Typical of the work of chiropodists was the report from Camp Crowder, Mo., covering the August–December 1943 period. During this time, two chiropodists carried out 5,416 treatments, including 2,478 for corns and calluses; 303 for ingrowing toenails; 496 for verrucae; 186 for epidermophytosis; and the remainder for miscellaneous conditions. Shields were applied in 1,254 cases, and 1,024 Arch-O-Graph arch supports were made; these supports were not so useful as had been anticipated, however, and their issue was discontinued on 31 December 1943.

As these data show, the work of chiropodists, even though strictly limited, took an appreciable burden off professional orthopedic personnel. The Camp Crowder experience was duplicated at many other installations.

Inspections and Evaluation

One of the most important phases of the visits to orthopedic sections of hospitals by the Consultant in Orthopedic Surgery, Surgeon General's Office, was the on-the-spot evaluation of orthopedic personnel in respect to training, experience, ability, performance, and appropriateness of assignment. On this basis, it was necessary, in five instances, to recommend the replacement of the chief of the orthopedic section of a general hospital. Objections to each of the recommendations were raised, as might have been expected, but in each instance, it was possible to prove its justice and wisdom. This particular problem, like many others, was settled more readily and more amicably when the visit to the hospital was made in company with the service command surgeon, as was possible in a number of instances.

Inspections are discussed in considerable detail later in this chapter (p. 68), but several summarized reports relating to personnel might be cited here.

At Ashford General Hospital, which was visited on 4 November 1943, the orthopedic service had 532 patients, 220 of whom had just been received. There were four orthopedic officers, which gave an average of 133 patients per officer, far too many. The absolute minimum should be 1 : 100, and a ratio of 1 : 75 was preferable. Under the circumstances, surgery was necessarily behind schedule. The assignment of an additional ward officer and an additional qualified orthopedic surgeon was recommended to assist Major Kelly, who should, however, be continued as chief of service.

At Rhoads General Hospital, Utica, N.Y., visited on 10 March 1944, the chief of the orthopedic section was Capt. (later Maj.) Newton C. McCollough, MC, B3153. At this time, he had had no formal training in orthopedic surgery, was not Board-certified, and was not a Fellow of the American College of Surgeons, but he had had 10 years of private practice in this specialty, including industrial surgery, had excellent judgment, a sure knowledge of the subject, and a familiarity with the orthopedic literature that compared very favorably with that possessed by formally trained men of his age. Captain McCollough was assisted by six other officers, including a Board-certified surgeon (in charge of the penicillin and officer wards) and two others with some orthopedic training. Eight newly inducted officers had just been assigned to this section for training. The present staff was doing excellent work, but if a certified orthopedic surgeon of exceptional ability should become available, his assignment would strengthen the section. When Maj. Robert Perlman, MC, was assigned to the service, Captain McCollough welcomed his arrival and continued as his assistant.[6]

Ashburn General Hospital, McKinney, Tex., was visited on 9–10 December 1943, in company with Colonel Waring, Consultant in Orthopedic Surgery, Eighth Service Command. This was a well-staffed and well-conducted service. The chief of section, Maj. (later Lt. Col.) Vernon P. Thompson, MC, was an excellently trained orthopedic surgeon. One of his two assistants had had surgical but not orthopedic training; the other was an orthopedic surgeon. With the additional help of two temporary duty officers, this service was regarded as well covered for the present.

The report from another general hospital, visited in December 1943, is a decided contrast to the reports just cited:

The chief of the orthopedic section in this hospital was a general surgeon, without either the training or the experience necessary for this assignment. His two assistants were also lacking in experience. Specifically, the following criticisms and recommendations were made:

1. Administrative changes should be made in the operating room arrangements and procedures. The orthopedic wards should be decentralized. Changes should be made in the handling of roentgenograms. Occupational therapy and rehabilitation programs, now nonexistent, should be instituted promptly.

2. Pneumoarthrograms had been made before operation in about 140 cases and repeated after operation in a number of instances. Analysis of operative findings showed poor correlation with the interpretation of the arthrograms, and it was recommended that this practice be discontinued at once. The procedure, regarded by many orthopedic surgeons as of small diagnostic value, probably explained the unusually large number of knee operations performed in this hospital. Much knee surgery was too radical, and no successful instance of ligament reconstruction was observed. More surgery was being done than was regarded as necessary in non-line-of-duty conditions.

[6] Captain McCollough continued in orthopedic surgery after the war and was certified in 1957.

3. A number of operations were observed. A Nicola operation, not performed by the standard technique, was too traumatic. In a knee operation, a normal medial meniscus was excised before it was discovered that it was the lateral meniscus that was torn. Two bone grafts, both done in the presence of infection, had been followed by osteomyelitis, and it was thought that both would fail.

4. Roger Anderson splints were used unwisely, and in the presence of infection.

5. Immobilization was unnecessarily prolonged in both knee and elbow injuries.

6. Quadriceps muscles were uniformly deficient in strength after operation.

7. Patients with fractures of the vertebral bodies were not being taught hyperextension exercises.

8. An ankle deformity was observed in a patient with a supracondylar fracture of the femur, in which plating had failed.

These situations and procedures were discussed in detail with the chief of the surgical service, and recommendations, in which he concurred, were made for their correction. The principal recommendation was that the present chief of the orthopedic section should be replaced promptly by a well-qualified, conservative orthopedic surgeon, who would cooperate with the chief of the surgical service.

The inefficiency with which this orthopedic section was run illustrates (1) the folly of appointing personnel with improper training and judgment to positions of responsibility and (2) the value of the consultant system, which, in this instance, permitted the prompt correction of objectionable practices. In all fairness, the personnel of the orthopedic section should not be blamed for them. The error was in the original appointments, which were made before a Consultant in Orthopedic Surgery was appointed in the Surgeon General's Office and before clarification of specialties was fully established.

TRAINING

Early Training Plans

There was scarcely a consultant in any specialty who would not have agreed that one of his most important functions was his training mission. Consultants in orthopedic surgery were in complete agreement on this point. The explanation was the large numbers of medical officers recently inducted from civilian life, some of them, as already mentioned, with only limited clinical experience and many of them with no orthopedic training. It was essential, moreover, that not only these officers but also experienced clinicians conduct their surgery by Army requirements. Chaos would have resulted if each of them had been permitted to handle injuries and perform operations according to his own desires and previous practices, without regard to the problems involved in combat injuries, including rapid evacuation and disposition. Methods and procedures had to be standardized as

much as possible in a system of medical care in which different medical officers handled the casualties at different stages of management.[7]

Concern over training in orthopedic surgery had been expressed even before the United States entered World War II. On 5 July 1940, Col. (later Brig. Gen.) Charles C. Hillman, MC, wrote to Dr. Bennett, in reply to a proposal the latter had made with Dr. Leadbetter, concerning ordering small groups of medical officers to Walter Reed General Hospital from various camps and posts for short, intensive courses in orthopedic surgery (*29*). Colonel Hillman did not think the idea practical at this time. The Personnel Division, Surgeon General's Office, was making every effort to obtain Reserve medical officers to supplement the Regular Army Medical Corps in carrying out the necessary medical activities connected with the present expansion of the Army. The Medical Corps was still 900 officers short of needs. As a result, every garrison was so low in personnel that there was little chance of withdrawing any officers, even for short periods of intensive training. Nothing more seems to have come of the idea at this time.

At the meeting of the Subcommittee on Orthopedic Surgery, Committee on Surgery, Division of Medical Sciences, National Research Council, on 11 October 1940, there was a detailed discussion of the military training of young, well-trained orthopedic surgeons and of the effects of the draft on medical students and interns (*30*). It was proposed that, after these persons had been trained in fractures and first aid, they be classified, rated, and organized into units, and that a listing of their availability be submitted to the Surgeon General's Office. No clear-cut decisions were arrived at.

At the second meeting of the Subcommittee on Orthopedic Surgery, on 1 December 1941, a week before Pearl Harbor, training was not mentioned (*31*).

As soon as the United States entered the war, the situation changed, and the need for additional trained orthopedic surgeons and other specialists became urgent (*32*). On 23 January 1942, faced with the necessity of training these specialists as rapidly as possible, The Surgeon General requested the Division of Medical Sciences, National Research Council, recommend to him medical colleges equipped and qualified to provide effective instruction in various specialties, including orthopedic surgery, and also recommend the length of the courses and formulate suitable outlines of instruction.

The Subcommittee on Orthopedic Surgery took its responsibilities very seriously. At the meeting on 24 February 1942 (*33*), the discussion was entirely specific, and the schools and personnel recommended were, almost

[7] It is only fair to say that a great deal had been accomplished in the field of trauma before the war by a number of surgical agencies, such as the Fracture Committee of the American College of Surgeons, though, naturally, the teaching was slanted toward civilian, not military, necessities.

without exception, the ones at which the courses in orthopedic surgery were finally given. They included:

Harvard Medical School, Boston, Dr. Ober and Dr. Marius N. Smith-Petersen.
Columbia University College of Physicians and Surgeons, Dr. Darrach.
Northwestern University Medical School, Chicago, Dr. Magnuson.
Washington University School of Medicine, Dr. J. Albert Key.
Tulane University School of Medicine, Dr. Caldwell.
University of California Medical School, Dr. Abbott and Dr. Frederick C. Bost.
University of Pennsylvania School of Medicine, Philadelphia, Pa., Dr. Walter E. Lee.
Johns Hopkins University School of Medicine, Dr. Bennett.
University of Michigan School of Medicine, Ann Arbor, Dr. Badgley and Dr. (later Col., MC) Grover C. Penberthy.

The training program for medical officers without training in orthopedic surgery was discussed again in detail at the 2 June 1942 meeting of the subcommittee (*34*), the discussion this time covering equipment and supplies necessary for students in these courses.

Courses of Study

The discussion on the contents of the proposed courses and the type of instruction consumed most of the day at the 24 February 1942 meeting of the Subcommittee on Orthopedic Surgery (*33*). At the end, every point was agreed on, so that *teaching would be uniform.* It was recommended that the faculty appointed for these courses should be orthopedic surgeons with some teaching experience, and it was also recommended that a coordinator should be appointed for each teaching group, to organize the teaching on the basis of subjects and hours and to see that the schedule was carried out as planned. In effect, both recommendations were implemented.

Three weeks were to be utilized for "the teaching of fractures and traumatic surgery as it pertained to orthopedic principles." At least 144 hours were to be utilized as follows:

1. Anatomy, "both applied and physiological and pertaining to the extremities," 48 hours.
2. Preparation and application of various splints, and preparation, application, and storage of plaster, 20 hours. At the 2 June 1942 meeting of the subcommittee (*34*), it was recommended strongly that student officers be taught how to prepare plaster properly and that they be required to apply plaster splints to each other and to remove them.
3. Care of wounds, 20 hours.
4. Fractures, simple and compound, and including surgical treatment, 48 hours.
5. Amputations, 8 hours.

At the 2 June 1942 meeting (*34*), there was a further discussion of how anatomy should be taught in these courses:

1. In combination with injuries as they occurred?
2. From the standpoint of surgical approach? (Dr. Darrach was prepared to teach anatomy by dissection and cross-sectional work.)

3. As applied anatomy? (Dr. Smith-Petersen intended to use specially prepared specimens, combined with demonstrations by dissection.)
4. By practical application in the clinic?

It was finally decided that the instructors, all of them experienced teachers, could determine best what form anatomic instruction should take in their own courses.

Operation of the Training Courses

By the end of June 1942, facilities were available in 22 civilian medical schools for the teaching of eight courses in orthopedic surgery specially designed for medical officers (*32*). The courses could not be inaugurated until 28 September, however, because of shortages of officers who could be spared to enroll in them. It had been called to the attention of the Subcommittee on Orthopedic Surgery at the 2 June 1942 (*34*) meeting that only 2 percent of the medical officers on extended active duty could be detailed to schools at any one time.

During 1942–43, courses in surgery of the extremities were given at the medical schools listed above, as well as at the schools at the University of Illinois, Urbana, Ill.; the University of Chicago, Chicago; the University of North Carolina, Chapel Hill, N.C.; Stanford University, Stanford, Calif.; the University of Tennessee, Knoxville, Tenn.; the University of Wisconsin, Madison, Wisc.; Duke University, Durham, N.C.; the University of Oregon, Eugene, Oreg.; the Lahey Clinic; and the Mayo Clinic. The course at the Mayo Clinic covered general surgery and surgical specialties. The course at Columbia University was conducted in cooperation with New York University, New York, N.Y. By the end of 1943, all of these courses had been terminated.

Separate figures are not available, but during the period the schools were in operation, a total of 2,138 medical officers were enrolled and 2,049 were graduated.

An investigation of the nine schools originally selected for this program showed that the maximum number of students capable of being accommodated for each course ranged from 20 to 40 and the minimum from 15 to 20. Three schools preferred to have 15 students, four preferred 20, and the remaining two schools in the nine analyzed preferred 25 and 40 each. Three schools were willing to repeat the course every 6 weeks; two, twice a year; one, four to six times a year; one, four times a year; and two, as often as necessary.

Qualifications for Training

The War Department memorandum issued on 5 December 1942 (*35*) provided that medical officers selected for special training courses must be

under 50 years of age and must have "a keen desire to improve their qualifications." For any of the surgical specialties, a prerequisite was a minimum of a year's full-time training in general surgery or practical experience in this field. In the memorandum issued on 3 June 1943 (*36*), the age was dropped to 45 years and it was specifically stated that applicants for courses in surgery of the extremities must have had a minimum of a year's surgical residency following an internship or equivalent practical training. It also specified that the aptitude and prior training of the officer selected must be such that he would be able to complete the prescribed course with credit to himself and the service and would be fitted to apply the training he had received.

Selection of candidates for these courses was by the Training and Military Personnel Divisions, Surgeon General's Office, and was chiefly—and necessarily—on the basis of paper qualifications. For these and other reasons, the Surgical Consultants Division was never in favor of the program, taking the position that it was impossible to train surgical specialists in such limited periods.

Sample Courses

University of California.—While the schedules of these professional courses varied somewhat from school to school, the (third) course given at the University of California Medical School on 24 May–19 June 1943 (see appendix, p. 1015) may be cited as an example of a carefully worked out, comprehensive course, which had been altered in certain respects on the basis of experience in earlier courses. At that, it was surprising how few changes were found to be necessary. One addition was the required use of the library for amputations, and another was the greater emphasis on practical work.

Tulane University.—The courses at the Tulane University School of Medicine, New Orleans, covered the same general subjects included in other courses. Teaching was by a limited number of didactic lectures, ward rounds, and demonstrations of debridement, plaster techniques, special splints (including the Tobruk splint),[8] transportation techniques, and orthopedic radiology. The course in bacteriology, taught by Dr. Leah Schaefer, was outstanding and was of major importance in the first courses, when penicillin was not yet available and gas gangrene was still a frightening possibility.

The school at Tulane University was particularly fortunate in two respects:

1. Ample clinical material was always available on the teaching services at Charity Hospital of Louisiana at New Orleans, which is immediately adjacent to Tulane.

[8] This splint had a very limited field of usefulness. A plaster-of-paris spica bandage was infinitely superior for the transportation of casualties with combat-incurred fractures of the femur.—M. C.

2. Two members of its faculty had had actual wartime experience. This was a decided advantage, for many Zone of Interior personnel who taught these courses necessarily derived their knowledge of war wounds from manuals, reports, and case histories, and had had little, if any, experience with combat casualties.

Dr. Caldwell, Chairman of the Department of Orthopedic Surgery, had served overseas in World War I. His first experience was as a volunteer in the American National Red Cross hospital outside of Paris established by Dr. (later Lt. Col., MC) Joseph A. Blake. Later, after the United States entered the war, Dr. Caldwell served as a commissioned medical officer (1st Lt., later Capt., MC), also under Colonel Blake, in Red Cross Hospital No. 2 in Paris.

Early in January 1944, as civilian Consultant in Orthopedic Surgery to The Surgeon General, Dr. Caldwell visited four general and four station hospitals in the South and Southwest, in ample time for him to incorporate his observations of them into the final training course given at the Tulane University School of Medicine. Among his (composite) notations were the following:

1. The wisdom of limiting the type of surgery done in station hospitals. The surgery that originated in one general hospital was conservative and well done, but many of the procedures that had been performed on patients received in it from station hospitals were open to serious criticism. They included plating of a fracture of the olecranon with screws protruding into the joint surfaces; open reduction and plating of simple fractures 24 to 48 hours after injury; double-pin fixation above and below the site of the fracture, a procedure that had resulted in distraction of the fragments and nonunion; and plating and closure of wounds at debridement, procedures that were followed by osteomyelitis and nonunion.

2. Generally good amputation stumps, though in a few instances, traction had not been adequate, apparently because of failure to conserve all available skin. Secondary amputation at a higher level would be required in these cases.

3. Generally excellent management of old compound fractures with nonunion.

4. Excellently supervised reconditioning, including occupational therapy, with resulting high morale of convalescent patients.

5. Too much time spent by orthopedic surgeons, through no fault of their own, on paperwork and retirement boards. In some hospitals, as much as 50 percent of the surgeon's time was being spent on such matters, and his professional duties had to be relegated to others, many of them with adequate training but immaturity of judgment, who were too often inclined to perform open surgery rather than practice conservative therapy.

The second member of the Tulane University faculty with wartime experience was Dr. (formerly Lt., MC, USN) Jack Wickstrom, Instructor in Orthopedics;[9] he had been wounded on Guadalcanal in December 1942, while assigned to the 1st Battalion, 2d Marine Division, and had been discharged from the naval hospital at Mare Island, Calif., in time to partici-

[9] Dr. Wickstrom is presently (1968) Lee Schlesinger Professor of Orthopedics and Chairman of the Department at the Tulane University School of Medicine. In the preparation of this volume, he has been of material assistance to the Associate Editor, "United States Army Medical Department, Surgery in World War II," whose office is located at the Tulane Medical School.

pate in the final course given at Tulane. His observations during combat as well as during his long hospitalization proved extremely useful. They resulted, among other things, in the omission from the course of any instruction in the half-pin external fixation of fractures, the poor results of which he had observed in many cases at Mare Island hospital.

The usefulness of such current, firsthand observations, particularly the observation of errors and unwise practices, is readily apparent. They added greatly to the practical value of the course at Tulane and of courses in other hospitals in which similar experiences were available.

Other Professional Training

Some of the formal courses just described proved extremely useful. Others, as had been predicted, amounted to very little. The Surgical Consultants Division, Surgeon General's Office, which, as just noted, disapproved of the whole program, suggested that a more practical plan might be to assign medical officers with the proper background to specialty services in general hospitals for on-the-job training. Many orthopedic surgeons were thus trained—111 at Lawson General Hospital, Atlanta, Ga., for instance. The 1945 report of McGuire General Hospital, Richmond, Va., mentioned receiving medical officers in varying numbers and at irregular intervals for training in orthopedic surgery, which included some classes in anatomy at the nearby Medical College of Virginia.

At the 29 July 1943 meeting of the Subcommittee on Orthopedic Surgery (*37*), a proposal was made to set up special courses in various hospitals to train interns as battalion surgeons. By this time, the formal courses just described were in full operation, and the motion was voted down.

Orthopedic surgeons, like most other newly inducted medical officers, were handicapped in the beginning of their service by their ignorance of military requirements and their lack of appreciation of the need for them. Many of them had had satisfactory to excellent training in civilian teaching centers, and they were inclined originally to adhere strictly to the school of thought under which they had been trained, including such matters as open reduction, pin fixation, and plating of unduly large numbers of fractures, as well as closure of compound fractures seen within the so-called *golden period*. These practices could not be permitted in military surgery, and, once the new officers had been taught the need for standardization, they usually went along with both policies and practices.

Postwar Professional Training

As with other specialties, there were a number of problems connected with the return of orthopedic surgeons to civilian life at the end of the war. The Surgical Consultants (then Surgery) Division had recognized one of

them as early as March 1943. Circular Letter No. 76, of the Surgeon General's Office, published on 23 March 1943 (*38*), reflected the implementation of their concern in the arrangements made for the accumulation of credit toward certification by the medical officers serving in the Armed Forces. A Medical Officer's Service Record form, which could be obtained from the secretaries of the various certifying boards, when properly kept, would provide adequate and authentic data for eligibility committees of American specialty boards to evaluate the experience acquired by medical officers while in the service. It was clearly stated that credit would be granted only when this form had been properly kept and was submitted with the application for certification.

In December 1944, a joint committee was organized by the American Orthopaedic Association and the American Academy of Orthopaedic Surgeons to study problems of postgraduate education in orthopedic surgery after the war, with particular attention to officers who, on discharge, would need additional training to complete Board requirements for certification (*39*). The formation of the committee [10] was the outgrowth of many discussions by members of the Committee on Postgraduate Training in Orthopaedic Surgery, the American Academy of Orthopaedic Surgeons, the American Orthopaedic Association, and the American Board of Orthopaedic Surgery, Inc. Dr. Caldwell, Secretary of the board, had frequently called attention to the need for providing for officers separated from service who wished to specialize in orthopedic surgery.

The Surgical Consultants Division recommended, as the immediate solution of this problem, that, in lieu of formal refresher courses, medical officers returning from overseas be assigned to general or large station hospitals for further training in their specialties. This plan would take care of officers whose surgical experience in the war had been limited or who had done only administrative work.

The first activity of the committee was a survey of civilian facilities available for training. It was carried out with the aid of members of the association and the academy in all parts of the country and, when completed, revealed:

1. That many centers which had previously handled the training of considerable numbers of surgeons would no longer be able to train any at all.
2. That other centers could not train as many men as they had trained before the war. The explanation, like the explanation for the termination of all training, was that many visiting surgeons were in service and that quotas of procurement and assignment had made it necessary to curtail the number of residencies.
3. That a number of hospitals which had had no training programs in the past had applied to the Council on Medical Education and Hospitals of the American Medical Association for accreditation as training centers for orthopedic surgery. The council was investigating these hospitals as rapidly as possible and it was expected that a number of them would be accredited and increase the residencies available.

[10] The members of the committee, which represented both the American Orthopaedic Association and the American Academy of Orthopaedic Surgeons, were Dr. Ralph K. Ghormley, Chairman, Dr. Chandler, Dr. Paul C. Colonna, Dr. Leadbetter, Dr. James S. Speed, and Dr. Philip D. Wilson.

4. That material for training was available in many hospitals, as were staffs qualified to conduct the work, but for one reason or another, these institutions had never applied for certification.

The committee believed that its first effort should be to encourage organization and accreditation of orthopedic services all over the country in which facilities and staff met requirements. It was not its purpose, nor did it have the authority, to certify services for training in orthopedic surgery. Its intention, however, was to cooperate as closely as possible with the American Medical Association Council on Medical Education and Hospitals. It believed that three types of orthopedic training should be provided; namely, adult surgery, children's surgery, and the surgery of trauma, particularly of fractures.

The official position of the American Board of Orthopaedic Surgery, Inc., in respect to credit for service in the Armed Forces was expressed in Article 7, Section 4, of the Bylaws, as follows (*40*):

CREDIT FOR SERVICE WITH THE ARMED FORCES: Because in some instances applicants who served with the Armed Forces acquired good training in orthopaedic surgery, credits up to a maximum of two years may be allowed. Such credit, however, may be granted only on presentation of evidence that such service is, in the opinion of the Committee on Eligibility, equivalent to similar periods of approved residency training * * *.

(a) A year of orthopaedic experience with the Armed Forces, when approved by the Committee, may be accepted to replace one of the three required years of orthopaedic training.

(b) A second year of orthopaedic service with the Armed Forces may be credited as a year toward the practice requirement.

(c) Credit for military service will be considered for assignments covered between January 1941 and July 1946.

In spite of the endeavors to smooth their return to civilian life, Colonel Peterson noted in his official diary that officers leaving service were not always welcomed by their confreres who had not served, and that some of them were having difficulty in obtaining or resuming hospital appointments. A distressing number of young officers whom it had hoped to keep in service also resigned from the Army.

Training of Enlisted Men

Training for enlisted men in orthopedic surgery was, for the most part, of the on-the-job variety. Most technicians, corpsmen, and even wardmasters had had little or no training when they were assigned. Some of them were given the assignment because they had failed to measure up to the higher standard required for other assignments. Others were on limited duty for physical reasons. With enlisted men, as with medical officers, the problem of training was the same: how, when time was of the essence, to integrate into military orthopedic surgery men drawn from civilian life, with varying degrees of education, training, and experience, with widely

differing points of view, and with a minimum, if any, of military experience. In spite of these difficulties and handicaps, many enlisted men learned to do excellent work.

In most hospitals, particularly because changes of assignment were frequent, training was a continuous process. The policy followed at Camp Carson, Colo., which emphasized uniformity of procedure, was almost essential in teaching groups with such widely varied backgrounds. At Halloran General Hospital, the training program for enlisted men was more formal than in most hospitals. In addition to practical training, the men had orientation lectures by section chiefs and ward officers, and also had regular examinations, the results of which were reported to the post training officer.

DISSEMINATION OF INFORMATION

General Considerations

Logistics as well as clinical considerations required, as already pointed out, that the care of the wounded be standardized as much as possible. One implication of this requirement was that an important part of a consultant's teaching function was the exposition and interpretation of the directives on this subject.

The need for organized dissemination of information throughout the Medical Corps was brought to the attention of The Surgeon General on 9 June 1943 by Col. Arden Freer, MC, then Director, Medical Practice Division, Surgeon General's Office (*41*). In his presentation, Colonel Freer particularly stressed the importance of the rapid dissemination of information concerning new developments and the utilization of the statistical and other factual material continuously being received in the Surgeon General's Office from worldwide sources.

The acceptance of responsibility for education and training of newly inducted medical officers by the Surgical Consultants Division also placed upon it the responsibility of preparing instructional material in general surgery and the surgical specialties. This was not a one-time function. It was recurrent throughout the war and it involved several types of publications.

Publications

The Bulletin of the U.S. Army Medical Department.—The *Bulletin*, which became a monthly instead of a quarterly in October 1943, was the chief medium by which medical officers in forward echelons were kept abreast of medical events and advances, and its monthly issuance greatly increased its efficiency. The 90-odd articles prepared for it in the Surgical Consultants Division during the war included material on penicillin, new

techniques, new equipment, diseases, wounds and injuries, and statistical data and other information derived from all theaters and analyzed as to authenticity and value before its release. A number of the articles published were prepared in the Orthopedic Branch, including material on fractures, hand injuries, quadriceps deficiency, tourniquets, and new equipment.

Manuals.—Manuals, available when the United States entered the war or prepared during it, included:

War Department Field Manual 8–50, Splints, Appliances, and Bandages, 11 September 1940 (*42*).

War Department Technical Manual 8–220, Medical Department Soldier's Handbook, 5 March 1941 (*43*).

War Department Technical Manual 8–210, Guides to Therapy for Medical Officers, 20 March 1942 (*44*).

War Department Field Manual 8–50, Medical Department Bandaging and Splinting, 15 January 1944 (*45*).

War Department Technical Manual 8–290, Educational Reconditioning, December 1944 (*46*).

War Department Technical Manual 8–293, Physical Therapy for Lower-Extremity Amputees, June 1946 (*47*).

"Orthopedic Subjects," one of the military surgical manuals prepared by the Committee on Surgery, Division of Medical Sciences, National Research Council, which appeared in 1942 (*48*). Designed to furnish "essential up-to-date and reliable information regarding military surgery," it was well written by medical officers who had served in World War I and who were outstanding civilian orthopedic surgeons. However, it did not meet the needs of the current military situation. The Senior Consultant in Orthopedic Surgery, European Theater of Operations, U.S. Army, commented on it as follows (*1*):

> * * * With few exceptions, the book is simply a compendium of reconstructive procedures on the bones and joints, all of them suitable for performance only in fixed hospitals in the Zone of Interior. The text is almost devoid of specific directions for the care of these injuries in active theaters of operations. Debridement is excellently described and the importance of splinting compound fractures is emphasized. On the other hand, the observation, "Splints can be improvised at the scene of the accident if they are needed," is completely unrealistic. It fails to take cognizance of the fact that in military surgery there may be need, at any given point, for the simultaneous treatment of hundreds, and sometimes of thousands, of severely injured men. Wounds of the joints, which are a frequent and serious wartime injury, are dismissed in half a page; the discussion is totally inadequate. Acute and chronic hematogeneous osteomyelitis, which was practically nonexistent in World War II, occupies almost a third of the 290 pages of the text. Skeletal traction in the management of compound fractures, delayed primary closure of wounds over compound fractures, and similar subjects are not mentioned.
>
> The whole text, in short, although it purported to furnish the information necessary for orthopedic surgeons as they entered military service from civilian life, was chiefly written from the standpoint of civilian practice.

In view of the relatively useless and sometimes misleading material in this manual, it is perhaps just as well that its distribution seems to have been very poor.

Circular letters.—The Consultant in Orthopedic Surgery was responsible for the preparation of circular letters issued from the Surgeon General's Office dealing exclusively with orthopedic subjects. He also prepared the sections on orthopedic surgery in letters dealing with general surgical subjects.

TB MED's (*War Department Technical Bulletins*).—TB MED's devoted exclusively to orthopedic subjects included No. 10, dated 14 February 1944 (*49*); No. 22, dated 21 March 1944 (*50*); No. 133, January 1945 (*51*); and No. 137, January 1945 (*52*). TB MED No. 147, March 1945, "Notes on Care of Battle Casualties" (*53*), also contained a great deal of orthopedic material.

These bulletins were of great value to the Surgical Consultants Division and its specialty branches in fulfilling one of their most important functions, the definition of professional policies, a definition required because of the wide variance in the professional abilities of medical officers. This variance made it necessary to prohibit certain policies and procedures that were acceptable in civilian practice, but that might have led to disaster in military practice if they had been performed promiscuously.

Other publications.—Excellent teaching material on various orthopedic subjects was prepared by orthopedic surgeons in hospitals all over the country. One very superior presentation of this sort was "Fractures of the Femur, Non-Operative and Operative," prepared by Colonel Hart, for use at the Hospital Center, Camp Carson, in October 1945. Earlier, Colonel Hart, with Capt. A. Jackson Day, MC, and Capt. Udell M. Gessell, MC, had prepared excellent teaching material on fractures in general and on regional fractures.

Just as the United States entered the war, Dr. Magnuson was engaged in the fourth revision of his well-known textbook of fractures (*54*). With the approval of the Subcommittee on Orthopedic Surgery, and with the cooperation of several of its members, he was able to include a section on fractures which represented the best military opinion to date on this subject.

In April 1942, Col. Roger G. Prentiss, Jr., MC, who represented The Surgeon General at National Research Council meetings, suggested that it might be a sound plan for the Subcommittee on Orthopedic Surgery to publish an article on splinting, preferably in *The Bulletin of the U.S. Army Medical Department*, based on the conclusions arrived at at previous meetings of the subcommittee. This article, "Splinting and Transportation of Fracture Cases," was published in the *Bulletin* for April 1943 (*55*).

There was general agreement that it was unfortunate that the ETMD's (*Essential Technical Medical Data*) which proved so practical and useful overseas were never permitted in the Zone of Interior.

Review of manuscripts.—Another function of the Consultant in Orthopedic Surgery, Surgeon General's Office, was the review of manuscripts submitted by medical officers to be approved for publication (*56*). This

function represented a considerable expenditure of time. The manuscripts were reviewed for security, professional content, and presentation. While no censorship was exercised, it was obviously impossible to clear for publication papers that conflicted with the stated policies of the Surgeon General's Office. It was suggested sometimes that articles poorly presented be rewritten, and editorial guidance was offered. Single case reports, unless they were in some way exceptional, and reports of small numbers of cases were generally discouraged. It was requested sometimes that articles of special interest and usefulness be published in *The Bulletin of the U.S. Army Medical Department.*

Films and Film Strips

In addition to supervising the films for the amputation program (p. 865), the Consultant in Orthopedic Surgery supervised the preparation of material on plaster casts (Training Film 8–2080), and the application of the army leg splint (Film Strip 8–50).

Books and Journals

The requisition and supply of medical books and journals for libraries of Army hospitals were the combined responsibility of the Surgeon General's Office and the Service of Supply (*57–59*). When procurement through regular channels was supplemented by local purchases, the distribution was entirely satisfactory in the Zone of Interior. Hospital library service was supplemented by the loan service of the Army Medical Library (now the National Library of Medicine). The libraries of local civilian hospitals, medical schools, and medical associations almost invariably were cordial and helpful in the loan and use of their facilities.

MEETINGS AND CONFERENCES

The need for professional conferences during the war was clear. Multiple problems, both administrative and professional, had to be solved on the basis of experience as well as according to Army regulations. It was important to disseminate new techniques and new devices and equally important to disseminate information concerning devices and techniques that had proved unsuccessful and sometimes actually dangerous.

Hospital Meetings

Formal conferences were usual and necessary, but perhaps nothing equaled in practical value the meetings held once or twice a week, or sometimes daily, as part of hospital routine. They varied in form from hospital

to hospital. Combined orthopedic-radiologic conferences were particularly useful, as were conferences with other related specialties, such as general surgery and pathology. Weekly conferences were often attended by the entire hospital staff.

At McGuire General Hospital, where conferences seemed particularly profitable, there were three types:

1. A monthly combined administrative-professional meeting, with discussion of statistics, fatalities, and special cases.
2. A monthly medical-surgical staff meeting, usually with guest speakers.
3. A weekly professional meeting, with different sections of the staff responsible for the programs, and with great emphasis on case presentations.

Conferences formed an important part of the agenda of hospital inspections by the consultants. On his visits, Colonel Peterson made ward rounds with the chief of the orthopedic section and his assistants and, on a consultant basis, examined patients with special problems. At the conference that followed his visit, the quality of the orthopedic work was assessed, the adequacy of the clinical records was reviewed; new techniques were described and other special information was presented; and current local and general problems were discussed in an open forum. These conferences contributed greatly to the success of the professional program in all the installations visited. They gave all the staff the opportunity to express their own opinions, as well as to acquire knowledge from the general experience, and they helped to unify and standardize the system of orthopedic care through all the service commands.

At Lawson General Hospital, great stress was laid on the educational value of conferences. Conferences for the orthopedic surgery staff were held weekly, and conferences with the chief of the surgical service, every 2 weeks. The fullest advantage was taken also of the visits of the Fourth Service Command Consultant in Orthopedic Surgery and of other orthopedic surgeons. It was found a real stimulus to the morale of ward officers to have them present at these conferences and to meet the visiting surgeons.

Consultants' Conferences

At the conferences for service command consultants held under the auspices of the Surgery (Surgical Consultants) Div' ion in October 1943 (*16*) and October 1944 (*60*), a wide range of surgical subjects was discussed, with a great deal of attention paid to orthopedic surgery. This was reasonable; in his opening address at the first of these conferences, General Kirk, The Surgeon General, stated that 60 percent of combat injuries would be compound fractures. They must be treated in suspension traction, he emphasized, until they were consolidated, not in Russell traction or plaster, which would permit muscles to atrophy.

At both conferences, there were discussions of such administrative considerations as surgery for EPTI disabilities; disposition and discharge;

classification and assignment of personnel; functions of general and station hospitals; treatment of prisoners of war (which, The Surgeon General pointed out, must equate with the treatment of U.S. Army personnel); transfer of casualties from debarkation hospitals; demobilization (at the 1944 conference); and allied matters. Presentations of special orthopedic concern dealt with radiology, anesthesia, reconditioning, carpal navicular and lunate injuries, hand injuries, the use of penicillin in reconstructive surgery, and herniated nucleus pulposus (discussed by Colonel Penberthy and Maj. (later Lt. Col.) Barnes Woodhall).

Local Meetings

Whenever it was practical, orthopedic surgeons contributed to the meetings of local medical societies. At an annual meeting of the District of Columbia Medical Society, for instance, the orthopedic section at Walter Reed General Hospital presented an exhibit of fractures, bone grafts, and bone tumors. At a meeting of the Washington Orthopaedic Club in March 1943, the same section presented the results of the Roger Anderson technique and demonstrated both elective orthopedic surgery and special methods for the management of combat fractures in general, gunshot fractures of the femur, metal fixation of fractures, plastic freeing of the quadriceps muscle, and the Syme amputation.

Conferences Attended by the Consultant in Orthopedic Surgery

In his role as consultant, Colonel Peterson attended numerous other professional and administrative conferences (*61*), such as a meeting of the Committee on Fractures and Other Trauma of the American College of Surgeons; a conference on bone plates and screws at the National Bureau of Standards on 28 August 1944; a conference on shoe research at the Boston Quartermaster Depot and Lawrence Laboratory in March 1944; numerous conferences on the prosthetic program; and equally numerous conferences on physical therapy and rehabilitation.

SUBCOMMITTEE ON ORTHOPEDIC SURGERY

Six meetings of the Subcommittee on Orthopedic Surgery, Committee on Surgery, Division of Medical Sciences, National Research Council, were held between 11 October 1940 and 19 November 1943. Minutes were issued for each meeting. Later, the minutes were replaced by a *Bulletin of Orthopedic Surgery*, which was continued until the end of the war. By the fall of 1943, most of the interest of the subcommittee had been transferred to amputations and its further actions are reported under that heading

(p. 865). The meetings held on 29 July 1943 (*37*) and 8 September 1943 (*62*) also were devoted entirely to amputations and prostheses.

11 October 1940 (*30*).—Those in attendance at the first meeting of the Subcommittee on Orthopedic Surgery, as at subsequent meetings, included representatives of the Medical Corps of the Army and the Navy; representatives of other National Research Council committees and subcommittees; and civilian orthopedic surgeons, most of whom were also teachers in medical schools. Dr. Bennett was elected Chairman.

Dr. Lewis H. Weed, Chairman of the parent Division of Medical Sciences, opened the meeting by explaining the need of the services for immediate information concerning surgical and other therapeutic methods, with particular reference to chemotherapy.

By this time, World War II was in its 14th month, but almost 14 months more were to pass before the United States entered the conflict. Dr. John Fulton, Professor of Physiology at the Yale University School of Medicine, New Haven, Conn., was leaving for England shortly. At the October 1940 meeting, he was bombarded with queries on which he was asked to secure information, including methods of transportation of casualties; treatment of shock; compound fractures; immediate equipment for use at the front; results of various therapeutic methods; transfusions; plasma; chemotherapy; the general setup of Army hospitals; training in the use of equipment; and "types of dressing with respect to paraffin."

A motion was passed to request "a concise statement for advice to medical students, interns, and residents with respect to entering the Reserve Corps to obtain a service for which they are trained and that this information came through the Information Committee of the National Research Council." The discussions on training at this and subsequent meetings are reported under that heading.

The other business of the first meeting of the subcommittee concerned the revision of the orthopedic section of a general field manual (presumably War Department Field Manual 8–50) and a report on the organization of physical therapists with a progress report of this specialty to date.

1 December 1941 (*31*). —The minutes of the subcommittee for its second meeting, 1 week before Pearl Harbor, have, in retrospect, a curiously unreal aspect. There was an extended discussion of research projects and fellowships in basic training for orthopedic surgery under the National Foundation for Infantile Paralysis. There was also a report, made "briefly," on the treatment of wounds in England and the use of plastic windows or plugs in plaster casts for the study of compound wounds. Colonel Kirk discussed transportation of fractures and splint traction after debridement. One questioner brought the membership of the subcommittee down to earth by raising the question as to how it would be possible to splint extremities during bombing raids, but the question was not answered. Instead, another question was raised, whether the solution of such a problem was consistent with the function of the subcommittee. Similarly, when equipment was

under discussion, it was indicated that this matter should be left to the Army, which, when it deemed it advisable, would ask the subcommittee for help or advice. The discussion is reminiscent of a similar discussion by the Subcommittee on Blood Substitutes, National Research Council, which, in April 1941, wondered whether any aspects of whole blood transfusion were within its province (*2*).

24 February 1942 (*33*).—At this meeting, largely devoted to training, Dr. Abbott gave a comprehensive report on the status of Pearl Harbor casualties returned to the United States (p. 263). A research project on the use of plastics in splints was rejected.

2 June 1942 (*34*).—The highlight of this meeting of the subcommittee was the report by Col. J. A. MacFarlane, RCAMC, Chief Medical Consultant, Canadian Armed Forces, on (1) the techniques of management of certain wounds and fractures and (2) a most important and enlightening discussion of rehabilitation (p. 471).

The Conn pneumatic tourniquet, which had been demonstrated at an earlier meeting, was demonstrated again, and its approval was recommended (p. 57). After a demonstration of the Roger Anderson unit for military use, a motion to recommend it failed to pass. Several proposed research projects also were not approved. Also at this meeting, as at previous meetings, material for publication was discussed.

29 July 1943 (*37*).—The Veterans' Administration was represented for the first time at the July 1943 meeting of the subcommittee, its participation reflecting the interest of that agency in its future responsibilities for the veterans of World War II, particularly the amputees, whose management was discussed at length by General Kirk, now The Surgeon General. It was easy to see how the attention of the subcommittee would be directed for the future.

HOSPITALS

General Considerations

War Department Circular No. 165, dated 19 July 1943 (*63*), specified that patients who required specialized treatment or whose hospitalization was likely to exceed 90 days should be moved from station hospitals to general hospitals as soon as they were transportable, with due allowance for the distance from hospital to hospital, the available means of transportation, and the overload of local hospital facilities. The same directions were given in War Department Circulars No. 304 of 22 November 1943 (*64*) and No. 12 of 10 January 1944 (*65*). From the beginning to the end of the war, there were frequent complaints that the required transfers were effected too slowly.

All the War Department circulars just cited also specified that elective surgery "of a formidable type" should be performed only in general hos-

pitals. The orthopedic procedures and conditions included in this category (the listings were expanded as the successive circulars were issued) were major amputations, operations on the joints, internal fixation of fractures, bone grafting, bunions, fractures of the facial bones, compression fractures and dislocations of vertebrae, fractures of the pelvis, and fractures of the shafts of the long bones. Excluded, if treatment could be completed within 90 days and if the facilities of the station hospital were adequate and the staff competent, were fractures of the shaft of the fibula (not of the tibia); fractures of metacarpals and metatarsals; uncomplicated Colles' and Pott's fractures; fractures of the forearm not requiring open reduction; and other simple fractures in which recovery was to be expected within the 90-day limit. A warning about proper splinting during transportation was added.

General hospitals were almost invariably well staffed with competent orthopedic surgeons. It was a waste of talent for surgeons of such competence to be assigned to station hospitals, where the work, as just indicated, was so sharply curtailed by the transfer of major orthopedic problems to general hospitals.

In practice, these regulations were found too restrictive to be followed in detail. Many station hospitals, because of their location, size, and trained personnel, were entirely qualified to perform the major procedures prohibited by regulations. Moreover, with the increase in combat casualties, general hospitals could not possibly care for all the major injuries that occurred in training camps. It was to solve these problems that the category of regional hospitals was established in April 1944, to care for Zone of Interior patients, while combat casualties were cared for in general hospitals (*66*).

Utilization of Hospital Beds

The effective use of hospital beds involved strict evaluation of the need for them by the casualties who were occupying them. The situation changed frequently, and it was an important function of the consultants in orthopedic surgery in the service commands, as well as of the Consultant in Orthopedic Surgery, Surgeon General's Office, to be sure that beds were properly utilized. During the 7 months in 1943–44 that he served as Consultant in Orthopedic Surgery for the Fourth Service Command, Colonel Cleveland visited some 60 hospitals. Like other consultants, he found a considerable number of patients with foot and back complaints on the orthopedic sections of general hospitals, where they did not belong. As late as 1945, a convoy from overseas handled at Brooke General Hospital, San Antonio, Tex., included a disproportionately large number of men with painful feet and backs. Many of them probably never should have been sent overseas. For the remainder, their problems were simply expressions of "neuropsychosis," and they did not belong in orthopedic surgery wards in general hospitals.

A considerable number of patients found in general hospitals when the consultants visited them should have been returned to duty from the station hospitals from which they had been transferred (*10*). Later, after convalescent hospitals had been established and with the increasing demands for beds in general hospitals for returned casualties, many men sent to these hospitals had to be readmitted later to general hospitals for additional definitive treatment. The situation made it important to assign to convalescent hospitals personnel who were properly qualified to decide on the disposition of patients—duty, readmission to a general hospital, or Certificate of Disability for Discharge.

Another important function of consultants in orthopedic surgery was to prevent undue prolongation of hospitalization. It was realized generally that the longer a casualty remained in the hospital, the more difficult it was to restore him to duty. Prolonged hospitalization was not tolerated well, either physically or psychologically. A soldier could readily remain an invalid mentally after he had completely recovered from a compound fracture. It was essential, therefore, that each casualty be appraised and his treatment planned with proper consideration of possible end results, so that his hospitalization would be no longer than necessary and its duration, whatever it was, would be justified.

Organization of Orthopedic Sections

The field of orthopedic surgery, as already pointed out, was well defined when the United States entered World War II. In the organization of Army hospitals, it was almost invariably a section of the surgical service, whose chief was usually a general surgeon. Only occasionally did the chief of a surgical service who controlled an orthopedic section consider himself competent, without special training, to override the judgment, and fail to utilize the abilities, of his orthopedic surgeon. Surgeons with only traumatic, or limited orthopedic, experience were assigned, as a rule, to station hospitals, in which the surgery permitted was limited. Surgeons with only limited orthopedic experience, or with none, were often slow to make definitive diagnoses, and there were occasional instances of unfortunate surgery, particularly elective knee surgery, when they undertook operations that were unnecessary or were contraindicated from the military point of view.

The chief of a busy orthopedic section carried a heavy load. He had to organize the section, very often train the personnel assigned to it, and establish cooperation among all those involved in the management of patients. The personnel, in addition to orthopedic surgeons and other medical officers, included wardmasters and other corpsmen; nurses; radiologists; X-ray and plaster technicians; physical and occupational therapists; and Red Cross workers, including Gray Ladies. Each time the service was disrupted, as it frequently was, by changes of personnel, major and minor

details had to be ironed out. Ward rounds, conferences, and similar activities took a great deal of time, but kept a service efficient.

All of these administrative matters formed the background of the professional duties of the orthopedic surgeon. Cooperation with other services, especially the neurosurgical and the plastic surgery services, was of great importance.

Hospitals for Specialized Treatment

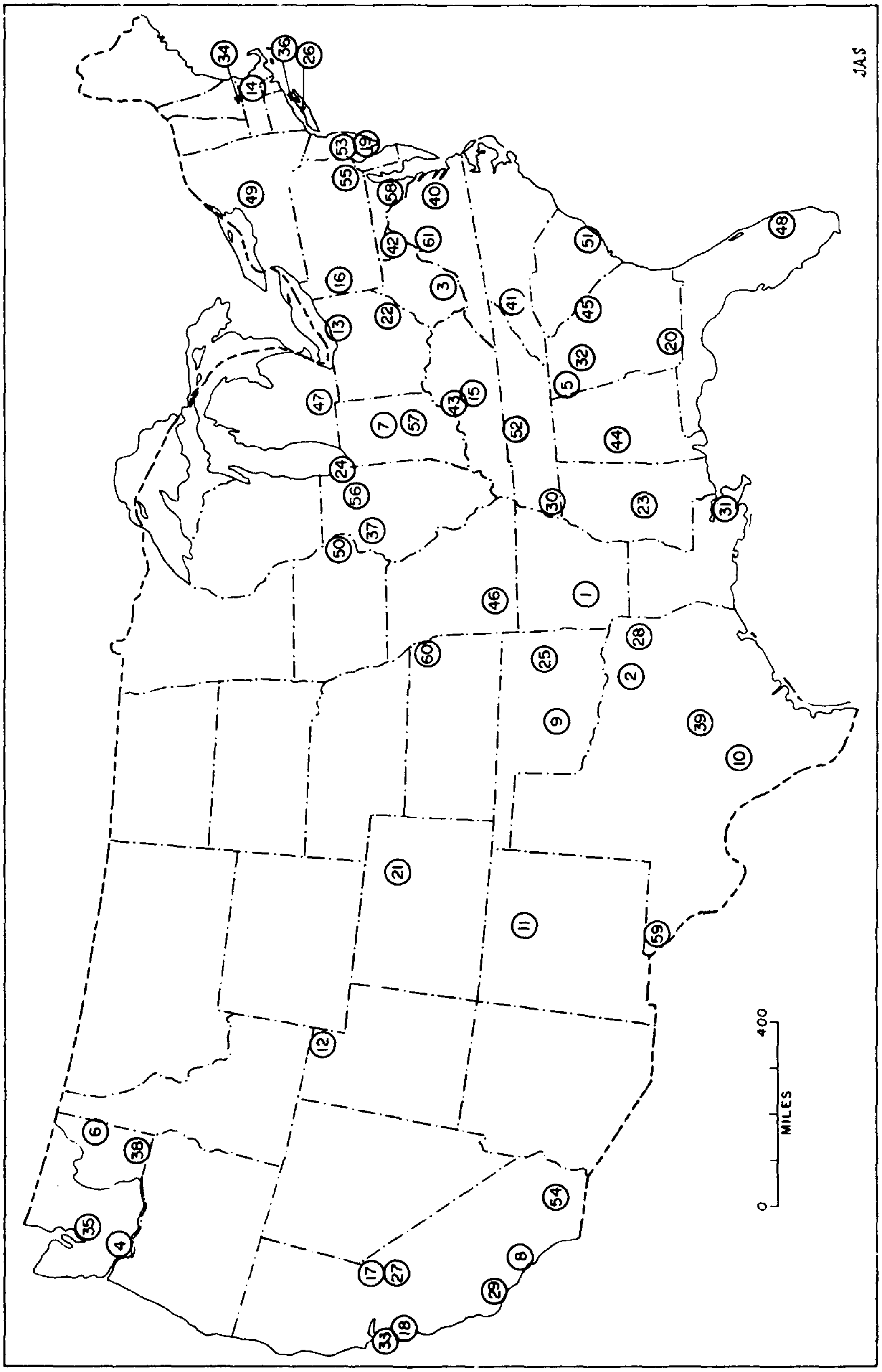
In the Zone of Interior (fig. 1), 33 named general hospitals were designated for orthopedic surgery; the same hospitals were designated for general surgery also. Of the 25 general hospitals designed as special treatment centers on 23 November 1943 (*67*), six were designated for both plastic and orthopedic surgery (William Beaumont at El Paso, Tex.; Bushnell at Brigham City, Utah; Letterman at San Francisco; Ream at Palm Beach, Fla.; O'Reilly at Springfield, Mo.; and Valley Forge at Phoenixville, Pa.). Five hospitals were designated for orthopedic surgery and neurosurgery (Halloran; Hammond at Modesto, Calif.; Kennedy at Memphis, Tenn.; McCaw at Walla Walla, Wash.; and Nichols at Louisville, Ky.). The Army and Navy General Hospital, Hot Springs, Ark., and Ashburn General Hospital were designated as arthritis centers in War Department Circular No. 347 dated 25 August 1944 (*68*).

All patients who needed specialized care were supposed to be transferred, as promptly as possible, to the general hospitals in which it was available. The original plan that patients be sent to hospitals nearest their homes had to be given up, in many instances, for logistic and other reasons, but it was generally followed.

Convalescent Hospitals

Although convalescent hospitals were not authorized in the Zone of Interior until April 1944, they had been evolving for many months earlier, in conjunction with station and general hospitals, in answer to the evident need for them and under such names as convalescent centers and convalescent annexes. At Thomas M. England General Hospital in Atlantic City, N.J., hotels had been leased for this purpose, and other hospitals had used other expedients.

Convalescent hospitals served several very useful purposes. They took patients out of the hospital atmosphere, which was undesirable for them as soon as their need for actual hospital care had passed. The transfer of these patients released hospital beds for other casualties and also freed specialists for the care of other casualties. The organization of such installations, free from a hospital atmosphere and a morbid environment, was one of the important medical-administrative contributions of World War II.



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54
35
4
8
17
27
29
18
33
JAS
0
MILES
400

FIGURE 1.—Named general hospitals in Zone of Interior in World War II:

1. Army and Navy, Hot Springs, Ark.
2. Ashburn, McKinney, Tex.
3. Ashford, White Sulphur Springs, W. Va.
4. Barnes, Vancouver, Wash.
5. Battey, Rome, Ga.
6. Baxter, Spokane, Wash.
7. Billings, Fort Benjamin Harrison (Indianapolis), Ind.
8. Birmingham, Van Nuys (Los Angeles), Calif.
9. Borden, Chickasha, Okla.
10. Brooke, Fort Sam Houston (San Antonio), Tex.
11. Bruns, Sante Fe, N. Mex.
12. Bushnell, Brigham City, Utah
13. Crile, Cleveland, Ohio
14. Cushing, Framingham, Mass.
15. Darnall, Danville, Ky.
16. Deshon, Butler, Pa.
17. DeWitt, Auburn, Calif.
18. Dibble, Menlo Park, Calif.
19. England (Thomas M. England after 14 Nov. 1944), Atlantic City, N.J.
20. Finney, Thomasville, Ga.
21. Fitzsimons, Denver, Colo.
22. Fletcher, Cambridge, Ohio
23. Foster, Jackson, Miss.
24. Gardiner, Chicago, Ill.
25. Glennan, Okmulgee, Okla.
26. Halloran, Willowbrook, Staten Island (Richmond), N.Y.
27. Hammond, Modesto, Calif.
28. Harmon, Longview, Tex.
29. Hoff, Santa Barbara, Calif.
30. Kennedy, Memphis, Tenn.
31. LaGarde, New Orleans, La.
32. Lawson, Atlanta, Ga.
33. Letterman, San Francisco, Calif.
34. Lovell, Ayers, Mass.
35. Madigan, Tacoma, Wash.
36. Mason, Brentwood, L.I., N.Y.
37. Mayo, Galesburg, Ill.
38. McCaw, Walla Walla, Wash.
39. McCloskey, Temple, Tex.
40. McGuire, Richmond, Va.
41. Moore, Swannanoa (Asheville), N.C.
42. Newton D. Baker, Martinsburg, W. Va.
43. Nichols, Louisville, Ky.
44. Northington, Tuscaloosa, Ala.
45. Oliver, Augusta, Ga.
46. O'Reilly, Springfield, Mo.
47. Percy Jones, Battle Creek, Mich.
48. Ream, Palm Beach, Fla.
49. Rhoads, Utica, N.Y.
50. Schick, Clinton, Iowa
51. Stark, Charleston, S.C.
52. Thayer, Nashville, Tenn.
53. Tilton, Fort Dix (Wrightstown), N.J.
54. Torney, Palm Springs, Calif.
55. Valley Forge, Phoenixville, Pa.
56. Vaughan, Hines (Chicago), Ill.
57. Wakeman, Camp Atterbury (Columbus), Ind.
58. Walter Reed, Washington, D.C.
59. William Beaumont, El Paso, Tex.
60. Winter, Topeka, Kans.
61. Woodrow Wilson, Staunton, Va.

It was Army policy that convalescent patients be kept under medical supervision and military control to insure proper adherence to the prescribed program and to maintain discipline, morale, and physical fitness. The experience at Walter Reed General Hospital showed the necessity for such a policy. As soon as the Forest Glen (Md.) Section was opened as part of the post, in November 1942, all ambulatory orthopedic patients were sent there; by March 1943, the local daily census was running between 200 and 300. The grounds were extensive and unfenced, the atmosphere was much like that of a hotel, and the pleasant informality led a number of patients to become absent without leave. The problem was solved readily. Experienced drill sergeants were put in charge, and every Saturday morning extensive ward rounds, lasting 2½ or 3 hours, were held, during which every patient was seen personally.

While patients with all varieties of wounds were sent to convalescent hospitals, the major proportion of casualties in most of them were orthopedic. An enormous burden was taken off the main hospitals by the operation of these convalescent hospitals; and with military control exercised over them, the patients were quickly restored to duty or were otherwise disposed of.

After his tour of convalescent hospitals in May 1945 (*69*), Colonel Carter, Assistant Director, Surgical Consultants Division, advised that these hospitals should be as independent as possible of the general hospitals near which they were located except for (1) such consultations as were indicated and (2) the transfer to them of patients who needed special care from the convalescent hospitals. The majority of patients in convalescent hospitals, in his opinion, should be cared for and disposed of without any help from the general hospital staff. The staffs of the two installations should be entirely independent of each other. Too much interlocking, as was evident in one or two hospitals that he had visited, led to discontent, professional jealousy, and general confusion.

In some hospitals visited by Colonel Carter, patients were observed only at long and irregular intervals, sometimes as long as 20 to 30 days. The lack of attention was detrimental to the morale of the patients and was equally undesirable for medical officers. Another error was that there was no continuity of care: The same officer frequently did not see the same patient again. Continuity of care was impossible in combat zones overseas but entirely possible in the Zone of Interior, in which it was highly desirable that a patient-physician relation be established and maintained. The soldier-patient was free from many worries that frequently attend the hospitalization of civilians: His pay continued while he was hospitalized, he had no medical bills, and he knew that, if he were permanently disabled, he would be compensated for the disability. These and other advantages, however, could be vitiated by carelessness in the patient-physician relation, which was particularly important to foster in convalescent hospitals, where its stimulus would expedite the patient's recovery and its lack could delay it.

Colonel Carter was particularly impressed by the organization and operation of Welch Convalescent Hospital, Daytona Beach, Fla. Here, the care of patients, who were segregated according to their injuries, was on the company level, administered by company medical officers under the supervision of the chief of the Surgical Service, Lt. Col. Robert W. McCullough, MC, who had had sound orthopedic training. Each company medical officer saw all patients in the company at least once a week, visiting one barracks each day. At frequent, stated intervals, all the patients in the company were seen on rounds by the chief of the Surgical Service, who was accompanied by the company medical officer and the battalion surgeon. This plan made the patients feel that they were receiving active medical attention, maintained a highly desirable patient-physician relation, and relieved the medical officers of the feeling, apparent in some convalescent hospitals, that they had been shunted from the main track of professional activity by this assignment.

Medical officers were also in charge of the patients' activities in the well-equipped remedial gymnasium and made full use of physical therapy personnel. Records were well kept, but the medical officers were so familiar with the status of their patients, all of whom they knew personally, that reference to papers was seldom necessary.

The morale of officers, enlisted men, and patients at this hospital was most inspiring and could be traced, in large part, to the enthusiasm and leadership of Colonel McCullough.

Special Hospital Experiences

Policies and experiences at certain hospitals are worth describing.

McGuire General Hospital.—At McGuire General Hospital, bed patients were seen on the wards as soon as possible after consultations were received. Ambulatory patients were seen by appointment in the clinic, held daily between 1000 and 1200. There was, thus, no loss of time and no futile waiting.

Fitzsimons General Hospital.—At Fitzsimons General Hospital, Denver, Colo., officers were treated in private rooms but on the same wards as enlisted men. It was an unusual arrangement, but it seemed to operate satisfactorily.

Halloran General Hospital.—Halloran General Hospital served as both a general hospital and an evacuation hospital. A large proportion of the casualties were orthopedic, and whenever convoys were received, there were endless days and nights of work, including paperwork, to prepare the patients for evacuation to other hospitals. During 1943, when the staff was composed largely of new officers, the situation frequently was difficult. In 1944, the Chief of the Orthopedic Section, Colonel Carpenter, pointed out that the evacuation policy then in effect did not permit complete treatment of patients on duty or living in the vicinity of the hospital, even though their care would be completed promptly. No action was taken on his suggestion that consideration be given to allotting a certain number of beds for the treatment of these men at Halloran General Hospital instead of evacuating them to other hospitals for this purpose.

Billings General Hospital.—At Billings General Hospital, Indianapolis, Ind., the orthopedic section wards were further subdivided, as follows:

1. A ward (wards) for the treatment of infections, especially osteomyelitis. This ward cared for patients who, after their infections had been controlled, were to have sliding skin grafts, pedicle grafts, dermatome grafts, bone grafts, arthrodeses, arthroplasties, and other operations.
2. Dermatome wards, so-called, which held most of the patients treated previously in the wards just described. These patients represented an intermediate stage between bone infections and final reconstructive surgery.
3. Clean surgical wards, containing patients ready for operation. The dermatome wards were the chief feeders for these clean wards, but many patients were admitted directly to them from other sources.
4. Femur wards, two or three of which were usually in operation. The patients in these wards were segregated because of the special care required in their management, including the management of equipment and special exercises. Personnel competent in these functions were assigned permanently to the femur wards.
5. Wards for ambulatory patients, including newly arrived patients in recent convoys who required screening to determine their current status and future course, as well as patients who were receiving physical therapy before transfer to convalescent hospitals and other disposition.

Other hospitals used somewhat similar plans.

CLINICS

General Considerations

The dispensaries attached to various military units were responsible for daily sick call. Treatment was not a dispensary function, and men who required it were referred to the clinics attached to station and general hospitals.

These clinics, as the Consultant in Orthopedic Surgery, Fourth Service Command, remarked in his 1943 report, varied directly in size with the strength of the post and inversely with the competence of unit surgeons and their ability to handle their own problems. Some clinics in this command saw as many as 2,000 patients a month and, in effect, held sick call for regimental and other unit surgeons unable or unwilling to examine their own patients intelligently.

The chief function of undermanned and overworked orthopedic clinics should have been to afford consultation service on difficult bone and joint problems. Clinic duties absorbed a large part of the time and energy of orthopedic surgeons, who should not have been expected to serve as members of disposition boards or in post dispensaries to solve outpatient problems. Complaints concerning the misuse of clinics were as frequent in the Army Air Forces Medical Corps as in that of the Army Ground Forces.

Workload

The workload of outpatient orthopedic clinics frequently was very heavy. Their population varied according to objective symptoms, subjective symptoms, and symptoms without any foundation at all. In the Fourth

Service Command, foot disabilities represented about 70 percent of the cases, back complaints from 15 to 20 percent, and other bone and joint disabilities the remainder. These proportions varied, particularly in regional hospitals, in which large numbers of troops in training were treated.

At Fort Belvoir, Va., which Colonel Peterson visited on 25 April 1944, from 1,000 to 2,000 inductees were being received every 2 weeks. The outpatient orthopedic clinic, which operated every day, occupied 75 percent of the time of two orthopedic surgeons, who at that could not keep up with the load. On this date, there was a backlog of 417 consultations, a most unfortunate situation, for there is nothing worse for soldiers, especially newly inducted soldiers, than sitting around doing nothing. The explanation of the workload was twofold: (1) the lack of proper screening in dispensaries, and (2) the tendency to send too many patients to the clinics because, at this time, from 1 to 2 percent of the soldiers sent to staging areas were being returned for physical reasons.

McCloskey General Hospital, Temple, Tex., began to receive patients on 20 October 1942. During 1943, 1,056 consultations were requested on hospital patients, 1,034 consultations and treatments on military outpatients, and 197 consultations on civilian outpatients. This clinic served as the treatment and consultation room for patients from other sections of the hospital as well as for outpatients. Every endeavor was made to keep patients on duty and to keep the ward census from clinic sources at a minimum.

The orthopedic clinic at Percy Jones Convalescent Hospital, Battle Creek, Mich., which was activated on 10 March 1945, had handled 3,893 patients by the end of November and had requested 4,740 roentgenologic examinations on them. As the following tabulation shows, the preponderance of examinations of the knee, leg, and foot was notable:

Shoulder	182	Knee	729
Clavicle	8	Patella	17
Scapula	17	Cervical spine	8
Humerus	245	Dorsal spine	37
Elbow	223	Lumbar spine	137
Radius-ulna	235	Sacrum	2
Wrist	195	Sacro-iliac	19
Hand	335	Coccyx	8
Ilium	5	Tibia and fibula	685
Ribs	3	Ankle	401
Pelvis	26	Foot	682
Hip	35	Os calcis	56
Femur	327		

At this hospital, the chief of the orthopedic service served as medical officer in the clinic. Appointments were made by companies, and the company medical officer attended when his patients were examined, to furnish information, make suggestions, and note recommendations.

Recommendations for further treatment in the clinic included physical therapy; occupational therapy; remedial exercises; application of braces, mechanical corrective devices, casts, or splints; and, sometimes, psychotherapy. Neuropsychiatric patients with complaints of orthopedic symptoms required careful study, to make certain that their symptoms were not founded on physical conditions.

Routine

It was imperative, because of the large numbers of patients treated, that outpatient clinics be organized on an efficient assembly line basis. Camp Crowder was typical. After the hospital was activated in February 1942, both surgical and orthopedic clinics were held three afternoons a week. By the end of the year, they were occupying an entire building, and the orthopedic clinic was operating 5 days a week. In 1942, more than 8,000 patients were seen in these two clinics and were given an average of three treatments each. In 1943, 11,732 patients were seen, and 18,199 treatments were given, of which 12,348 were given to 7,223 orthopedic patients.

By this time, the orthopedic clinic was well organized. As the patients entered, they were seen at the admitting desk by two clerks, who assembled charts, previous records, roentgenograms, and consultation requests, and distributed them to the waiting rooms, which were separated for clean cases, infected cases, and foot cases. Here, the patients undressed and prepared for examination. The general orthopedic examinations were carried out by two orthopedic surgeons; and the foot examinations, by a third. Orthopedic examinations averaged 100 a day; on one occasion, 165 were made.

The clinic was equipped with two dictating machines, and the findings in each case were dictated as soon as the examination was completed. Recommendations for roentgenologic examinations, consultations, and treatments were typed at once by the clerks.

Emergencies (fractures, sprains, dislocations, and complaints of severe pain) took precedence over all other cases.

As many as eight enlisted men were assigned at a time to the orthopedic clinic. They worked under a technician, third grade, who served as noncommissioned officer in charge. Their assignments, fortunately, remained almost constant, and their competence had much to do with the efficient operation of the clinic.

FACILITIES AND EQUIPMENT

Facilities

Facilities for orthopedic departments were on much the same order in all Zone of Interior general hospitals. They consisted of separate wards

for enlisted men and officers; waiting and examining rooms; plaster rooms; rooms for minor surgical procedures; X-ray rooms and darkrooms for quick development of films; provision for fluoroscopy for closed reduction of fracture in some hospitals, though this technique was officially forbidden; and office space for the chief of section, his assistants, and his secretary and other clerical help.

Because of the haste with which new hospitals were constructed early in the war, plus failure to consult knowledgeable orthopedic personnel, some serious deficiencies were present in the first buildings erected. Plans for some hospitals provided no plaster rooms, and it was necessary to use needed ward space for the application of casts. Some plans did not provide for X-ray facilities adjacent to, or as part of, the orthopedic sections. In one hospital, through some misconception of what was required, a small plaster dispenser of the dental type was provided for the orthopedic section of the X-ray department.

Deficiencies were gradually corrected as time passed, and facilities generally were adequate, and even excellent, when it became the practice to seek the advice of the Consultant in Orthopedic Surgery, Surgeon General's Office, while plans were still being made.

On the other hand, facilities that were adequate in quiet times often were strained to the limit when casualties were heavy. On 4 July 1945, Lt. Col. Marvin P. Knight, MC, wrote Colonel Peterson that, unless larger examining rooms, plaster rooms, and other facilities were provided, Crile General Hospital, Cleveland, Ohio, "would continue to be a madhouse when convoys were received."

Equipment

At the end of the war, it was the opinion of orthopedic surgeons that the equipment provided for this specialty in general, regional, and station hospitals in the Zone of Interior ranged from excellent to superior.

All hospitals had equipment for bone surgery in wide variety and of the most modern type. All general and regional hospitals, for instance, had Albee-Compere orthopedic tables and most of them had two electric motor saws. Both wooden and metal Balkan frames were in ample supply, as were Thomas splints for both upper and lower extremities. Portable X-ray equipment was available on all fracture services. Walkers were standard equipment on rehabilitation services.

Standardization and supply.—The happy situation just described did not prevail early in the war. One of the first duties, and one of the most important continuing duties, of the Consultant in Orthopedic Surgery, Surgeon General's Office, had to do with equipment (*10*). It was necessary for him to catalog and standardize all the items used in braceshops and artificial limb shops. These were new needs, which had to be worked out in cooperation with the Medical Supply Division, Surgeon General's Office,

before any requisitions could be filled and a satisfactory supply system set up. Major items, such as fracture tables, and apparently minor items, such as hinge joints and rubber bumpers for prostheses, often required the same amount of time and effort for their procurement and seemed of almost equal importance. Conferences were necessary almost daily with the Medical Supply Division. Most of them were informal, and during them, much was accomplished on the writing of requirements, specifications, and procurement.

At the conferences of the service command consultants in 1943 (*16*) and 1944 (*60*), a good deal of time was devoted to the discussion of orthopedic equipment, particularly new equipment. Many new items were tested on orthopedic services before they were standardized or rejected. This task took considerable time, but it proved efficient and rewarding.

New equipment.—All proposals for new orthopedic equipment were referred to Colonel Peterson, who noted wryly in his official diary that "the enthusiasm of the inventor usually bore no direct relationship to the appropriateness of his device for use in the military service." On the other hand, from the standpoint of both orthopedic surgery and good public relations, careful consideration of all such suggestions was necessary, to be certain that appliances of merit should not be overlooked. The suggestions covered a wide variety of items, including substitutes for army splints and for plaster of paris, shoes with coil springs, and special types of arch supports (neither in the service nor out of it did it ever seem to be realized that arch supports would never make a combat soldier). Suggestions of real merit from distinguished orthopedic surgeons sometimes had to be rejected because, while they would be useful in civilian practice, for one reason or another they did not meet military needs or were not practical in military orthopedic surgery.

Shortages and defects.—It was the practice to investigate all complaints of shortages and deficiencies of equipment. Frequently, however, the complaints either could not be substantiated or could be explained by the failure of individual officers to request supplies to which they were entitled because they were unfamiliar with what was available. Colonel Peterson pointed this out at the service command consultants conference in 1943 (*16*). He granted that part of the difficulty could be traced to inadequacies of the current supply catalog, particularly the unsatisfactory indexing, but he expected this trouble to end when the revision presently underway was completed. The efficiency of a central supply room was generally agreed on.

Shortages in some hospitals could be explained by excesses of items in other hospitals. On 4 February 1944, General Rankin wrote to Colonel Penberthy, Consultant in Surgery, Seventh Service Command, that his attention had been called to an enormous amount of duplicate equipment scattered throughout all the hospitals of all service commands, and that he desired that all of them be surveyed at once from this standpoint (*70*).

If excess equipment was found, the kind and number of each item were to be reported to the Surgeon General's Office, and the supply officer of the hospital was to return the excess to the proper depot. On their next visits, service command consultants were to check this situation, and The Surgeon General was to be notified if the directions had not been carried out.

Supposed shortages frequently were found to be no more than lack of the equipment to which individual orthopedic surgeons had been accustomed in civilian life, but which had not been standardized. Individual desires, of course, could not be catered to. Many new instruments and other equipment nonstandard before the war were rapidly standardized and rushed into production, but the policy had to be the procurement of what would be safest and most useful for the greatest number of medical officers.

A great deal of orthopedic equipment was made of critical materials, and difficulties of procurement provided still another explanation of shortages and delays in delivery. Shortly after the United States entered the war, for instance, sheet aluminum, then specified for splints (item No. 37650), was allocated by the War Production Board exclusively to airplane manufacturers. The Medical Department could no longer purchase it, and the stocks on hand were reserved for hospitals maintaining orthopedic shops, to which it was doled out.

One piece of equipment about which there was general and justified dissatisfaction was the Holophane light used over the operating table. Tests showed that, in 30 minutes, it raised the temperature 18° F. at the level of the surgeon's head and about as much at the level of the operating table.

Defects in materials for internal fixation are discussed under that heading (p. 384).

Plaster Bandages

At the beginning of the war, plaster was procured in bulk and bandages were prepared locally in all hospitals. The arrangement was inefficient. It required a great deal of space and also usurped the time and attention of personnel needed for more pressing and more sophisticated duties. Many ingenious devices to expedite the preparation of bandages were suggested, but most of them did not meet the requirements that the bandages must be uniform and must contain a sufficient amount of plaster to be effective. As soon as factory-rolled bandages began to be sent overseas, a clamor arose for their use in Zone of Interior hospitals, not only to save time and effort but also because the commercial bandages were of better quality and were uniform. Despite persistent efforts, it was not until the war was almost over that commercial plaster bandages were provided for Zone of Interior hospitals.

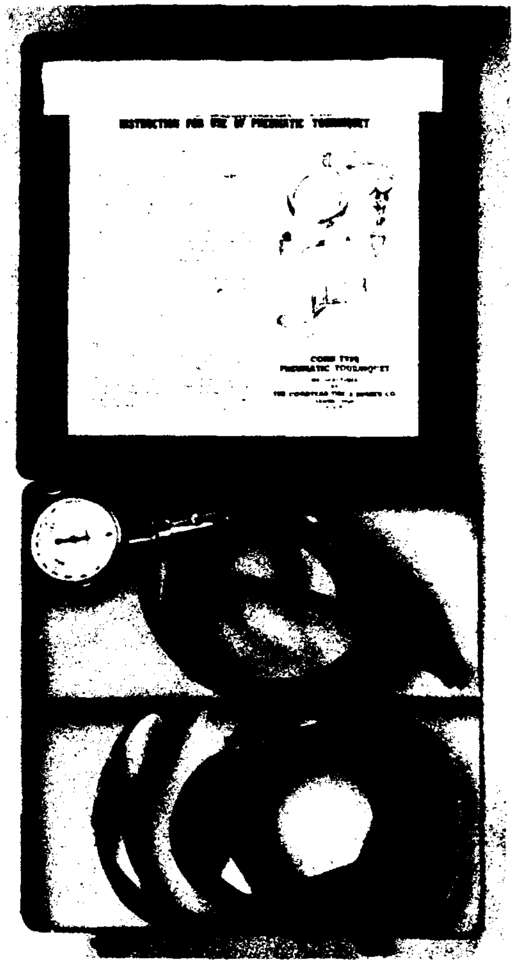

FIGURE 2.—Conn pneumatic tourniquet standardized for Army use in 1945. Tourniquet disassembled in carrying case. Note instructions in cover.

Tourniquets

Damage to soft tissues, nerves, and blood vessels by tourniquets used during operation was a problem throughout the war. In February 1944, General Rankin called the attention of the service command consultants to this risk and mentioned two instances of such damage that had recently come to his attention (*70*). In both instances, tourniquets had been used on the thigh during operations on the knee of very long duration. He questioned whether the use of a tourniquet during operation on the cartilages of the knee was necessary at all.[11] He directed that the whole question of tourniquets be looked into and that any posttourniquet palsies be reported to him.

[11] This was an orthopedic practice of long standing and in general use.—M. C.

At the 2 June 1942 meeting of the Subcommittee on Orthopedic Surgery (*34*), Dr. Conn, of the subcommittee, demonstrated a pneumatic tourniquet that he had devised to lessen the risk of paralysis and gangrene, always a possibility when conventional tourniquets were used. The subcommittee recommended its acceptance, standardization, and provision at battalion aid and collecting stations, as well as at forward and other hospitals. This tourniquet (fig. 2) consisted of a pneumatic sleeve with a valve of the football bladder type; it was inflated and deflated by a hand-operated, pump-type bulb, with a pressure gage attached. It was not accepted, however, when it was first recommended, in June 1942, for two reasons: it required the use of rubber and other critical materials, and its use was dependent on the constant availability of personnel to operate the pump. Within the next year, the Goodyear Rubber Co., disregarding the possible military utilization of the tourniquet, made up several models, which later were modified, for civilian physicians. Discussion of the tourniquet continued at subsequent meetings of the Subcommittee on Orthopedic Surgery without any immediate progress. The obvious, civilian-minded suggestion that a preliminary order for the Army be given the manufacturer was not possible under Army regulations, which required that all items of equipment be inspected and tested for practicality under field conditions. This preliminary process eventually was accomplished and the tourniquet was standardized and manufactured, but it was not delivered until the spring of 1945.

Even when this pneumatic tourniquet became available, occasional cases of posttourniquet paralysis were reported after its use at excessive pressure or for unusually long periods. Four such cases were reported to the Consultant in Orthopedic Surgery, Fourth Service Command, three of the lower extremity and one of the upper. In each instance, the paralysis was transient.

It was Colonel Peterson's advice in all the hospitals he visited that only pneumatic tourniquets be used, that they be used only on strict indications, and that only the prescribed minimum pressure should be exerted.

BRACESHOPS

General Considerations

Braceshops, as distinguished from shops for artificial limbs (p. 883), were a most important adjunct of all orthopedic service. Some experienced orthopedic surgeons, in fact, expressed the opinion after the war that they did not see how so many civilian hospitals had previously managed without them, and they recommended that thereafter they should be part of the planning for all fixed military hospitals.

Inspections of braceshops were always part of the visits of the Consultant in Orthopedic Surgery, Surgeon General's Office. Between Sep-

tember 1943 and November 1944, he covered 40 in his tours. All inspections were made with the idea that these shops were essential parts of the orthopedic surgery service.

In some hospitals, such as Cushing General Hospital at Framingham, Mass., and Lovell General Hospital at Ayers, Mass., the orthopedic braceshops were part of the original setup and provided splints and braces for all installations in the First Service Command (*71*). In August 1944, a shop was authorized at the Waltham Regional Hospital, Waltham, Mass., to provide for its own needs and the needs of adjacent station hospitals, but it did not become actively operational until January 1945. As a rule, about 6 months elapsed between authorization of a braceshop and its activation.

Work was particularly heavy at the hospitals that were also neurosurgical centers (*5*, *6*) and hand centers (*72*) because of the need for supporting apparatus for paraplegics and for casualties with hand and peripheral nerve injuries. Splints and braces for these patients usually had to be designed to meet their individual problems and could not be turned out in bulk.

After Colonel Peterson's first tours of hospitals, his comments were somewhat the same on most of them:

> The space was generally adequate, with one or two exceptions, for present needs. It would not be adequate when, as was anticipated, casualties increased sharply. Some hospitals already had provided for this contingency. The personnel of the shops generally was inadequate quantitatively and sometimes qualitatively. It was recommended that additional trained personnel be sent to all of them. There were numerous shortages of equipment, a great deal of which was on order. In one hospital, the equipment list was still in the Medical Supply Section and had never been brought to the attention of the chief of the orthopedic section there. Generally speaking, the braces turned out were well made and of high quality, even though much of the work was being done by only partially trained technicians.

After his tours in May 1944, Colonel Peterson's comments on braceshops almost uniformly were favorable. In the single hospital in which the braces were below standard, the shop was being operated by an incompletely trained medical officer and a civilian of equally limited experience.

Personnel

The efficient operation of braceshops depended upon the competence of their personnel, and trained technicians for them were in very short supply. This particularly was true early in the war, when most of the shops were in charge of civilian employees, who worked most commendably for very long hours, performing their own duties and instructing Army personnel, who later were able to produce highly satisfactory braces and other equipment. Many of these military trainees, incidentally, carried their Army skills back into civilian life and continued to practice them there.

At the end of the war, in Army hospital braceshops, there were some 66 civilian personnel and some 765 enlisted men. It had not been a simple task to provide them:

1. The first plan to increase the supply of bracemakers was to set up schools in which to train them (*73*). Formal schools were set up at Barnes (Vancouver, Wash.), Beaumont, Billings, Hoff (Santa Barbara, Calif.), Kennedy, LaGarde (New Orleans), Lovell, and O'Reilly General Hospitals. Later in the war, as casualties continued to mount and shortages of trained technicians persisted, training was conducted at practically all hospitals which needed them. Up to February 1943, the training of these mechanics was the responsibility of the Surgeon General's Office. Then, it was transferred to the service commands (*74*).

Enlisted men were selected for training because of their mechanical aptitude and previous experience in metal or leather work. The course of instruction, which covered 12 weeks, was chiefly practical. It was gratifying to see how professionally proficient most of these trainees were at the end of the course.

2. Every endeavor was made to hold in the shops men with special training. At both Lovell and Cushing General Hospitals, it was possible to make special arrangements with the Personnel Division, Headquarters, First Service Command, to protect these scarce categories from changes of assignment (*71*). At Ashford General Hospital, on the other hand, in April 1943, an orthopedic mechanic was saved from transfer (being made without the knowledge of the chief of the orthopedic section) only by his fortuitous development of measles.

3. Some thought was given to training Wac's (Women's Army Corps) to become bracemakers, but nothing came of the idea. Enlisted women, however, proved very useful as administrative assistants in the braceshops and on orthopedic sections.

4. In some hospitals, training was on a production line basis, each man being trained in turn in every aspect of bracemaking. Later, the production line plan permitted the utilization of special skills in special parts of the process.

5. In POW (prisoner-of-war) hospitals, bracemaking was carried out by prisoners, under the direction of U.S. Army personnel. At some hospitals, such as Woodrow Wilson General Hospital (Staunton, Va.), POW's worked in the braceshops.

In spite of all these efforts, shortages of bracemakers continued throughout the war. They were listed as critically needed specialists in ASF Memorandum No. 193, dated 26 June 1944 (*75*), and in War Department Memorandum No. 615–44, dated 25 July 1944 (*76*). The use of limited service personnel for this work was mentioned in the June 1944 memorandum. In ASF Circular No. 287, dated 2 September 1944 (*77*), it was stated that the importance of bracemakers' work could not be overestimated and that those so qualified possessed "one of the scarcest of critical skills." Still another War Department memorandum (No. 615–45 of 2 February 1945) listed orthopedic mechanics (SSN366) among "Critically needed specialists" (*78*).

Grades of braceshop technicians were inconsistent with the work they were doing, and attention was called to this in ASF Circular No. 287 (*77*). It was recommended that consideration should be given "to reviewing present suballotments of grades to hospitals within each service command." In spite of other recommendations and correspondence on the subject, ratings continued at about their original levels throughout the war (*79–82*).

General hospitals, exclusive of amputation centers, usually began with six-man shops, but, by the end of the war, most of them had at least nine men, and a few had 20. Regional hospitals, particularly those in training areas, usually began with three-man shops, which, when the need became evident, were enlarged to six men. Most convalescent hospitals had only small shops operated by one bracemaker.

Equipment

The frustrating delays in the procurement of equipment for braceshops are set forth in detail in correspondence among The Surgeon General, General Rankin, and Col. Edward Reynolds, MAC, Chief, Supply Service.

In a lengthy memorandum, dated 18 October 1944, Colonel Reynolds stated that improvement had occurred in the equipping of braceshops, but the situation was still unsatisfactory, and hospital commanders who were directed to operate these facilities were justifiably disturbed (*83*). "The fact is," he continued, "there was inadequate planning and preparation for the equipping and supplying of these activities in advance of their activation."

The result, in Colonel Reynolds' opinion, constituted "the notable failure" of the Supply Service over the past 18 months. The real fact, General Rankin commented bluntly, was that, up to the fall of 1943, there had been no planning at all (*84*).

In his summary of the development of the current situation, Colonel Reynolds noted that, in the spring of 1942, Colonel Kirk, then Chief of Surgery, Walter Reed General Hospital, submitted a list of braceshop equipment and supplies to the commanding officer of this hospital, who submitted it to The Surgeon General. No action was taken on it. On 1 May 1943, the Supply Service, of the Surgeon General's Office, authorized distribution depots to approve requisitions for very limited amounts of equipment for braceshops in hospitals of a thousand or more beds but not for smaller hospitals.

In June 1943, Professional Service, of the Surgeon General's Office, notified the Supply Service that there was no definitive policy for the issuance of such equipment. In July 1943, the Supply Service undertook central procurement of these supplies, using a list furnished by Walter Reed General Hospital.

In early September 1943, when it had become evident that this list was unsatisfactory, it was referred to Colonel Peterson, who had just been appointed Consultant in Orthopedic Surgery, Surgeon General's Office, and, as already stated, one of his first duties was its revision (*10*). The revised list then was submitted to a board appointed by the Surgeon General's Office Order No. 169, dated 21 September 1943. As soon as the list was approved, the Supply Service published a list of the named general hospitals and the six station hospitals approved by Professional Service for distribution of the equipment. The Supply Service also furnished distribution depots with copies of the list, indicating that it would notify the depots as items on it became available, so that requisitions would be made only for those items. This list made no provision for 12 general hospitals which, according to Professional Service records, were operating braceshops and had adequate equipment for them. It also held allocations down to equipment for six technicians per hospital.

When the original list was revised further in January 1944, due allowance was made for variations in the numbers of orthopedic surgeons at the various general hospitals. The revision also provided equipment for more than six technicians at each amputation center.

In the spring of 1944, an officer at the St. Louis Medical Depot, who had had some experience in civilian life with supplies for orthopedic shoes, was ordered to the Surgeon General's Office to work out specifications and purchase descriptions for items already procurable and to make recommendations and draw up specifications for other items for which there was apparently universal need. This work was completed in July 1944.

Procurement.—It was never a simple matter to perform such a task because of the Army regulations covering it (*85*). The final braceshop list was processed through the Catalog Branch and Technical Division, Surgeon General's Office, was approved by the Requirements Branch, Army Service Forces, on 30 September 1944, and was in press in October 1944, when the correspondence with The Surgeon General just summarized was initiated by Colonel Reynolds.

The list, with few exceptions, provided all the equipment necessary for braceshops in the Zone of Interior and was also used for several shops sent overseas. It did not, however, immediately solve the procurement problem, as the correspondence under discussion indicated.

Colonel Reynolds explained the difficulties and delays connected with the procurement of this equipment: To avoid the considerable work and the delays connected with standardizing every article in the original lists, the Technical Division and the Supply Service, Surgeon General's Office, had tried to conduct procurement on a nonstandard basis, although Army regulations permitted this method only on "spot, one-time requirements" (*86*). In April 1944, Army Service Forces declined to permit further procurement on this basis, and the Technical Division was obliged to require all orthopedic shop equipment and supplies to be purchased by standing operating procedure, which consisted of a number of rather cumbersome steps:

1. Upon advice from the Professional Service Division of the Surgeon General's Office, or any other source, the Technical Division decides that an item should be standardized, after which the following steps are taken:

a. Procurement Assignment Board action, which determines the responsibility for requirements, funds, specifications, storage, issue, and maintenance.

b. Approval from Army Service Forces.

c. Determination by the Technical Division of the basis of issue.

d. Determination by the same division, in collaboration with the Requirements Branch, Supply Service, of the quantities necessary for initial and maintenance supply for the installations authorized to have the items in question. Since quantities purchased are computed from a firm basis of issue, distribution must be on the same basis. Any issue to an authorized installation, or in excess of the authorized quantity for a particular installation, can be made only to the detriment of some authorized user.

e. Inclusion by the Supply Service of the item in question in Army Supply programs. This service forwards the requirements to the Inventory Control Branch

for issuance of the purchase authorization to the Army Medical Purchasing Office or to the Technical Service charged with responsibility for procurement of the item.

2. Whenever an item is newly standardized, a purchase description, and specifications, including packaging specifications, must be compiled before purchase can be accomplished. Approval of the description by the Technical Division is necessary before purchase.

3. When purchase responsibility is assigned to the Medical Department, the Army Medical Purchasing Office accomplishes the contract. When the item is assigned to another Technical Service, the Inventory Control Branch submits the requisition to it.

Cumbersome and time consuming as these steps were, experience proved that short cuts and attempts to move outside of regular channels, especially when another agency was involved, simply produced delays and confusion that required extraordinary efforts to correct, frequently at the expense of other materials being processed through regular channels.

The difficulties that arose in connection with braceshop equipment also extended to equipment for occupational therapy and for reconditioning, and for much the same reasons.

In October 1944, Colonel Reynolds stated in his memorandum that equipment for braceshops then was fairly adequate, but new items would not be available for several months. Also, no provision had been made for the possible inclusion in the program of additional regional hospitals. He listed existing deficiencies as caused by:

1. Preferences of individual orthopedic surgeons for special equipment which was not standardized and for which the majority of surgeons had expressed no desire.

2. Curtailment of previously authorized local purchases.

3. Provision of material not in accord with specifications, especially certain steels and rubbers, as the result of unauthorized substitutions.

4. The time requirements for procurement and the inability to procure some items. Thus, 51 items lacking on 10 January 1944 still were not available on 31 October 1944.

5. The needs of regional hospitals. These hospitals were first designated on 7 June 1944 (*66*). On 5 July, recommendations were made for authorization of braceshops in them, but the shops could not be established because of lack of equipment. The situation could have been avoided only if these hospitals had known of their designations months in advance of their authorization.

Local purchases.—Equipment required for orthopedic shops included material that lay, for the most part, outside of regular types of Medical Department items, such as tools, special steels, spare parts for laboratory equipment, leather, and certain other items in critically short supply, for one reason because the War Manpower and War Production Boards had limited their production for other than specified purposes.

These items ordinarily would have been purchased locally by the hospitals or by distribution depots. Volume of needs, however, increased so rapidly that, even for articles whose production was not limited, local resources were not adequate; and centralized procurement, with priorities and allocations, became necessary. If the change of purchasing policy had not already been forced upon the hospital braceshops by the curtailment just mentioned, War Department Circular No. 310, dated 20 July 1944,

would have put a stop to it (*86*). Most of the equipment needed for braceshops fell into the category for which exclusive procurement responsibility for War Department needs had been assigned.

Eventually, satisfactory arrangements were made for local procurement of certain supplies for braceshops except for the purchase of small quantities of steel and other materials not ordinarily needed by the Medical Department and not within the Health Supplies Rating Plan. In such instances, copies of the purchase order had to go to the Surgeon General's Office with the request for assignment of a preference rating (*87*), obtaining of which was sometimes a very slow business.

Lawson General Hospital Braceshop

Successive reports of Lawson General Hospital reflect the importance of a braceshop to a busy orthopedic section.

Construction was begun on this hospital on 15 December 1940. It received its first patients on 22 July 1941 and its first large increment on 5 August 1941. In 1942, 47 percent of the 2,513 patients admitted to the surgical service were on the orthopedic section.

In 1942, the braceshop, whose personnel included a number of enlisted men with mechanical ability on limited service, made 983 items, including 78 walking calipers; 81 lower leg braces; 200 sole and heel alterations; 147 arch supports; and 254 miscellaneous special appliances and repairs.

In 1943, the shop made 1,271 items, with about the same proportionate distribution. It now was set up in the orthopedic surgery building, and had separate metal and leather divisions. A school for orthopedic mechanics was established during the year, and at least three men were constantly in training; 14 had been graduated.

In 1944, the expanded braceshop, now three times its original size, was using 30 mechanics for bracework and prostheses. Four men were in training constantly for periods of 2 months each, and 18 were graduated during the year. The senior technician, a civilian, was awarded the Distinguished Service Emblem by the War Department.

The distribution of the items fabricated during 1944 was somewhat different from that of previous years. Included were 314 arch supports, 443 shoe alterations, 230 arm and hand braces, 133 special lower leg braces, 120 full length leg braces, and 145 miscellaneous items and repairs.

In 1945, aside from artificial limbs, 3,594 items were made, chiefly splints and braces for fractures, paraplegia, and peripheral nerve injuries.

All of this work was supervised by the senior orthopedic surgeon. The director of the shop, who was the chief of the amputation center at the hospital, was assisted administratively by a second lieutenant, MAC, and a WAC staff sergeant. A master sergeant supervised the shop personnel, which during the year consisted of 48 enlisted men and 22 civilians.

RECORDS

General Considerations

The keeping of adequate records was an integral part of patient care and one in which required standards were maintained only by constant vigilance on the part of those in authority.

A great deal of time and confusion was saved when the regulation was observed that an outline of the wound and of the fracture be drawn on the cast, with a notation concerning the nature of the fracture (simple or compound), the date of injury, the date and hour of debridement, and the name (number) of the unit that had treated the patient. Partly from lack of time and press of work, and partly from simple carelessness, this regulation often was breached, and a great deal of time was wasted in triage of the patient and in the later search for accurate information about his injuries.

Time was lost also and much trouble was caused when all the necessary records did not accompany patients, particularly when roentgenograms were not included in the records and when operative and progress notes were missing. Progress notes were extremely important in orthopedic injuries combined with nerve injuries. In the volume dealing with radiology in this historical series, Col. Kenneth D. A. Allen, MC, Senior Consultant in Radiology, European theater, has a great deal to say about the importance of moving roentgenograms and records with patients and on methods of accomplishing these objectives (*88*).

The Consultant in Orthopedic Surgery, of the Surgeon General's Office, commented adversely on the records in a number of hospitals which he visited. They were lacking in details, repetitious, and, at the same time, uninformative. Roentgenograms were not available always, and interpretations frequently were missing. Carelessness in regard to records sometimes delayed discharges for disability (Certificate of Disability for Discharge). Retention of men in hospitals for long periods to complete their administrative records wasted bedspace and was not in the best interests of the patients themselves. Colonel Peterson recommended that some means be worked out of discharging such men on the records available and completing their total records later.

After he completed his tour of convalescent hospitals in the Zone of Interior in May 1945, Colonel Carter recommended to General Rankin that an Army circular letter be prepared with the purpose of improving the "ghastly" records that were going along with patients to these hospitals (*69*). His recommendation was accepted and ASF Circular Letter No. 270, dated 14 July 1945 (*89*), pointed out the inadequacy and incompleteness of these records and the resultant need for medical officers in convalescent hospitals to spend time and effort in the attempt to garner the necessary data upon which to base further management. It was sometimes necessary to begin entirely new records.

This circular letter directed that any patient transferred from any Zone of Interior hospital other than a debarkation hospital to any other hospital must be accompanied by (1) a summary of his course in the hospitals in which he had received treatment; (2) specific recommendations for future treatment; and (3) specific recommendations for his final disposition. Every effort also must be made by debarkation hospitals to be

certain that all available medical and other records accompany patients in their transfer to general or convalescent hospitals.

Deficiencies in wartime medical records are, of course, understandable. The arrival or evacuation of large convoys caused some confusion and imposed a serious workload on duty personnel. Professional care of patients naturally took precedence over paperwork, however essential the records might be.

Proposed Clinical Investigations

At the first conference of the service command consultants in October 1943 (*16*), General Rankin stated that his office intended to request from the consultants information on various surgical subjects, in the hope that much useful information could thus be collected. The plan of studying large series of special types of injuries and other conditions unfortunately did not work out. Inadequacy of records, transfers of records with patients, changes in policies, and other reasons made it practically impossible to collect and analyze valid series. The annual report of the Surgery Division, Surgeon General's Office, for 1943–44 (*15*) mentioned that steps had been taken to study knee joint surgery by securing individual reports for all patients operated on for disabilities of the knee, particularly injuries of the semilunar cartilage and osteochondritis dissecans. Variations in surgical policies and techniques, in rehabilitation policies, and in adequacy (inadequacy) of records would introduce many undesirable variables, it was realized, but the project had other promising aspects, and forms were prepared for it and administrative details worked out. When approval was sought, however, from the Control Division, it was refused, and the project necessarily was abandoned.

This experience makes clear why in this series of historical volumes personally collected—and not officially recorded—series of cases usually are used for the analysis of certain conditions and procedures.

Although there was, for obvious reasons, no formal followup of patients except in such small personal series as those carried out at Fort Jackson, S.C. (p. 104), it was remarkable how often individual cases of special interest were reported back and forth.

DISPOSITION OF PATIENTS AND LIMITED SERVICE

Disposition Policies

Orthopedic surgeons, like other medical officers, had many functions other than professional duties. This was particularly true of officers in the upper grades, one of whose time-consuming tasks was service on dis-

position boards. Because of the large proportion of orthopedic patients in Zone of Interior hospitals, orthopedic surgeons were called on with great frequency for this duty. Halloran General Hospital is an example. In October 1944, in addition to his other duties, the Chief of the Orthopedic Section sat on nine disposition boards for officers, 13 for enlisted men, and 19 for nurses.

The policies on transfer of patients from hospital to hospital in the Zone of Interior and on their final disposition were set by the Surgeon General's Office. At the beginning of the war, the plan was to transfer patients unfit for immediate military duty to the Veterans' Administration for further treatment before discharge (*90*), but it soon became evident that this agency did not have either the facilities or the personnel to handle the large numbers of casualties who would require treatment. Late in 1943, therefore, the policies were changed "rather informally," and thereafter patients were kept under Army control until they reached maximum improvement. The new plan required prolonged hospitalization in Army hospitals, particularly for orthopedic patients; and except for strict supervision by hospital authorities and frequent inspections by the Consultant in Orthopedic Surgery, Surgeon General's Office, and the service command consultants, delays in disposition would have been even more frequent than they were. Early discharge from the hospital could be expedited by placing patients on leave or on furlough, which was good for them and which resulted in great savings in hospital bedspace.

Another common error in disposition was unnecessary transfer of patients, from station to general hospitals and from general to convalescent hospitals, when, in many instances, their treatment could have been completed at previous hospitals and they could have been discharged at once.

Patients often were reluctant to be transferred to Veterans' Administration hospitals, particularly before the policies concerning transfer were liberalized. They believed, rightly, that they could obtain better care in Army hospitals, and they also objected to the transfer for financial reasons; in many instances, their pay would decrease when they went off active duty. No Army regulations or other directives issued during the war provided for soldiers who did not wish to be treated in Veterans' Administration hospitals. ASF Circular No. 254, dated 4 July 1945 (*91*), explained the principles of disposition, but made no reference to the Veterans' Administration. Under the circumstances, when soldiers did not wish to be treated in Veterans' Administration installations, there was usually no choice but to discharge them without further Army hospitalization.

The disposition of officers and enlisted men was serious business. Too casual separation from service worked a hardship on the fighting strength of the Army. Retention in service of men who were incapable of performing their duties lessened Army efficiency and also worked a hardship on the soldier. Finally, malingering had to be considered a possibility in many cases, particularly those involving back complaints.

All disposition and retirement proceedings which reached the Surgeon General's Office and which, as a great many did, had orthopedic aspects were referred to Colonel Peterson for his opinion.

Limited Service

Part of the confusion attached to the disposition of many officers and enlisted men arose from the definition of limited service and its implications. In July 1943, in War Department Circular No. 161 (*92*), this term was withdrawn except for certain restricted purposes, though enlistment for limited service would still be permitted. The matter was discussed in detail at the conference of service command consultants in October 1943 (*16*) by Colonel Freer, then Director, Medical Practice Division, Professional Service, Surgeon General's Office. He explained that, in the future, this term would not appear on service records, though actually the status was still in effect and the enlisted man's record would contain a notation from the medical officer indicating the kind of duty he was capable of. Colonel Freer hoped very much that the term would be reinstated.

War Department Circular No. 164, dated 26 April 1944 (*93*), provided for the use of enlisted men according to their physical capacity. It also prescribed specific physical defects which would disqualify them for overseas service. It was assumed that a man could perform under field conditions if he had had no difficulties during his training period and since had not suffered "a marked physical set-back or deterioration." The list of defects and conditions disqualifying men for overseas service included no orthopedic conditions.

The selection of candidates for limited service overseas required sound professional judgment, combined with the exercise of commonsense. Neither was evident in, for instance, the clearance of a patient after an operation for herniated nucleus pulposus, who was instructed to do no heavy lifting. His value in an overseas theater was highly doubtful.

In this April 1944 circular, it was directed that the term "limited service" pertaining to "enlisted men" be discontinued except at Armed Forces induction centers, to correspond with the terminology used by Selective Service and by the Navy. The elimination of the term did not mean that men in this category would be discharged or that the Army would not continue to induct and use men who did not fulfill the full requirements for general service. No man would be discharged for physical disability if he met the minimum standards currently prescribed in Mobilization Regulations No. 1–9 of 19 April 1944 (*94*), which permitted induction with EPTI defects, among which many orthopedic defects were included (p. 93). Unfortunately, changing policies relative to physical and mental standards led to the induction of many men unsuitable for military service, who were discharged only after considerable expense, effort, and training.

INSPECTIONS OF HOSPITALS

General Considerations

In general, the standards of orthopedic treatment in Zone of Interior hospitals—as well as in hospitals overseas—were exceptionally high in World War II, and results were excellent. In most instances, combat casualties and other sick and wounded were treated adequately, with sound judgment, and with only occasional delays in diagnosis, treatment, and disposition. Candidates for surgery were selected carefully, and surgery was performed competently. The chief credit for his happy situation belongs to the excellent residency training program in effect in civilian hospitals for many years before World War II. It provided almost all the trained orthopedic surgeons who served as chiefs of section in the larger hospitals.

At any single time, a third or more of all patients in general and regional hospitals in the Zone of Interior were on the orthopedic sections. Appropriately, therefore, though by chance and not by advanced planning, at least a third of the time of the Consultant in Orthopedic Surgery, Surgeon General's Office, was spent in field trips. Of the 66 general hospitals in the United States, he made one or more visits to all but five.

The chief purpose of the consultant's hospital visits, each of which lasted from 1 to 3 days, was to examine the equipment; evaluate the competence of the personnel; review the professional work of the staff; and make recommendations in all of these fields.

Relations between the Consultant in Orthopedic Surgery in the Surgeon General's Office and surgeons of the various service commands, while usually cordial and amiable, had their times of stress. The command surgeons were naturally desirous of maintaining their authority, and they sometimes objected to the direct communications which the consultant had instituted as a matter of efficiency, especially in his supervision of amputation centers (p. 875), as well as in certain other areas. On occasion, service command surgeons complained to General Rankin, and the Consultant in Orthopedic Surgery was duly admonished by him.

In spite of such occasional difficulties, Colonel Peterson continued to carry on a very active correspondence with orthopedic surgeons in the Zone of Interior. These communications were invaluable to him in the performance of his official duties, and the two volumes in which they were ultimately bound have furnished much of the background material for this chapter and for the chapters on amputations (p. 865).

Colonel Peterson almost invariably was received with courtesy and cooperation by the commanding officers of the hospitals and their staffs, most of whom made it possible for him to carry out his mission pleasantly and expeditiously. The few occasions on which he was made to feel unwelcome were explained readily by local conditions, by harassing special prob-

lems, or, perhaps, by the overzealousness of the visitor himself. It often was apparent, however, that hospitals were burdened by the number of visiting consultants and others with professional and administrative missions. In particular, it seemed to Colonel Peterson that the descent of a number of consultants in various specialties at the same time, as in the wartime "Flying Circus" visits, was not entirely desirable. These massive inspections often lacked the personal contacts with patients and staff possible on individual visits, which generally were very profitable, both administratively and professionally.

In the Fourth Service Command, consultants once or twice were sent out as a team, at the request of the Service Command Surgeon, to make a general survey. On one such occasion, a newly opened general hospital in the command had received critical and unfair comment by a radio reporter, who simply failed to realize that the inadequate staff was overwhelmed by the reception of large numbers of casualties before the hospital was ready for them. The real error, which was overlooked, was that most of these patients should not have been sent to a general hospital. They could have been disposed of readily, most of them by return to duty, at the station hospitals from which they had arrived. At any rate, with the help of the visiting consultants, all of them were examined and disposed of promptly at the general hospital, and deficiencies in staff and equipment, including the shortage of orthopedic personnel, were corrected.

On another occasion, early in the war, all the consultants in the Fourth Service Command were sent to Stark General Hospital, Charleston, S.C., to observe the first casualties returned from North Africa. The visit was most instructive to the Consultant in Orthopedic Surgery in the command. At this time, all fractures of the long bones were being treated by the closed plaster technique, which was later abandoned. Many amputees had protruding bone ends because of failure to utilize skin traction on the stump.

In the Fourth Service Command, tours of inspection were often made jointly by the Consultants in Surgery and Orthopedic Surgery. When they made their visits separately, they called each other's attention to problems in their special fields.

Routine of Visit

After visiting the commanding officer of the hospital and securing his permission for his visit, Colonel Peterson made complete rounds on all wards. His examination and evaluation of the patients were greatly simplified when the orthopedic surgeon, his assistants, and the ward officers were thoroughly familiar with their patients and could brief him quickly on each one.

These ward rounds were useful in several respects:

1. The patients were very much interested in what they regarded, correctly, as the consultant's review of their condition. Great care, of course, was taken to keep all bed-

side comments general and to make no remarks that the patient might construe as reflecting unfavorably on his previous treatment or that he might misinterpret and attempt to use later in assignment and disposition.

2. Ward officers sometimes felt that they were the forgotten men of the war, and ward rounds with the visiting consultant, and the part they played in them, were excellent for their morale.

3. The rounds confirmed the chief of the orthopedic section in his judgments or, in difficult cases, helped him to resolve his doubts.

4. At the conferences held after ward rounds, general principles and policies were discussed, as well as the proposed treatment of individual cases. The value of a fresh point of view frequently was evident in the fact that, after the conferences, planned surgery for some patients almost invariably was modified, or perhaps omitted.

5. A great deal of informal teaching was done at these conferences as well as during rounds, but the visits of the consultant primarily were not didactic. In contrast, the visits made to selected hospitals by Dr. Sterling Bunnell, Consultant in Hand Surgery to the Secretary of War, were intended entirely for teaching. They are described in detail in the volume on hand surgery in this historical series (*72*).

The Consultant in Orthopedic Surgery was careful to give praise where it was due—as it most often was—but equally careful to speak plainly about violations of directives, unwise surgery, and other professional and administrative errors. These data were included in his report of his inspection of each hospital sent to The Surgeon General and also sent to the commanding officer of each hospital. All of these reports are on file in the Historical Unit, U.S. Army Medical Department, Walter Reed Army Medical Center, but certain details will be commented on in this chapter.

Administrative Considerations

Colonel Peterson's discussions of orthopedic personnel (p. 17), records (p. 63), conferences (p. 38), equipment (p. 53), and other matters appear elsewhere in this chapter, under the proper headings.

Other (summarized) administrative comments, usually applicable to more than one hospital, were as follows:

1. At some general hospitals, patients were found who could, and should, have been treated at station hospitals.

2. Also at some general hospitals were patients who obviously required disability discharges for combat injuries as well as for conditions preexistent to induction. Many of them should have been handled at station hospitals.

3. Patients who required open reduction for fresh fractures sometimes were sent to general hospitals as long as 4 to 6 weeks after injury. Since this procedure was not permitted in station hospitals, it was recommended strongly that some method be devised for expediting the transfer of such patients to general hospitals.

4. The large numbers of self-inflicted wounds encountered (40 at one hospital) required investigation and directives for their management. Although all such wounds were considered not line of duty by military regulations, Colonel Peterson recommended that every such case be carefully investigated.

5. At some general hospitals, many officers were observed who had been on limited duty for specific periods and had returned for reclassification. In many of these cases, reinstatement to full duty could have been automatic. The adoption of such a

policy would have relieved general hospitals of much time-consuming administrative work.

6. The workload in many hospitals was undesirably heavy. All orthopedic sections should have operated with at least one officer for every 75 patients, whereas in some hospitals visited, the ratio was as high as 1 : 133. At least a third of the officers assigned to orthopedic sections should have had training and experience in this specialty. It was notable that the severest criticisms of clinical management concerned orthopedic sections that did not meet this requirement.

7. The backlog of operations observed in some hospitals resulted from the overload just mentioned. In other hospitals, however, facilities were not being utilized to the fullest extent. When the census was low, it might be permissible to begin operating at 0830, but not when the hospital was crowded, as General Rankin pointed out in a letter to service command consultants in February 1945 (*95*).

8. Liaison with other sections of the hospital generally was excellent, particularly with neurosurgical sections. At one hospital, patients with herniated nucleus pulposus were being admitted alternately to the orthopedic service and the neurosurgical service, which Colonel Peterson frequently visited because patients on it also had orthopedic injuries and diseases. He considered that this practice showed lack of a definite policy and recommended that, for the future, all such patients be considered neurosurgical.

9. Operating room technique generally was good. Shoes were covered, masks were worn, patients were identified carefully, and skin preparation was excellent. Equipment generally was satisfactory. Additional equipment was recommended for a few hospitals, and at one, it was recommended that substandard sterilizers be replaced.

An exception to these satisfactory observations was the situation at a certain hospital in which there were no officers adequately trained in orthopedic surgery. The plaster room, on a Sunday morning, was very dirty. The plaster table evidently had not been cleaned for some time. Both clean and infected patients were handled in this room, which was on the main corridor to the operating rooms. The water had considerable rust in it. The operating room technique was careless, and not all the errors could be attributed to shortages of nurses. Street shoes were not covered. There was much body contact. Some patients were not marked clearly for identification.

Recommendations were made for correction of these errors, most of which could be eliminated with no trouble at all.

10. Training of inexperienced orthopedic surgeons generally was good, though in some hospitals, more direct instruction was needed on such items as ward administration, disposition of patients, and other medicomilitary matters. It was suggested that more use be made of experienced orthopedic surgeons for teaching. At Fitzsimons General Hospital, for instance, Major Hart made a valuable contribution to training because of his special qualifications, wide experience, and sound judgment, supplemented by the excellent teaching material he prepared.

11. Facilities for prisoners of war were examined carefully in all hospitals in which POW personnel were under treatment. The Surgeon General had emphasized at the conference of service command consultants in October 1943 (*16*) that the prisoners of war must be treated exactly as U.S. Army personnel were treated. Later, Glennan General Hospital, Okmulgee, Okla., and the hospital at Camp Forest, Tullahoma, Tenn. (Prisoner-of-War Hospital No. 2), were set aside for prisoners of war, which greatly simplified their care.

Clinical Considerations

Clinical comments, like administrative comments, apply, as a rule, to more than one hospital.

1. There was a rather general tendency to perform open reduction on simple fractures on indications that were often dubious, though the mere use of this technique in such fractures was not wrong in itself. It frequently was well justified. The treatment of choice in simple spiral fractures of the tibia, for instance, was open reduction and screw fixation.

In addition to the tendency to plate fractures when more conservative treatment would have been sufficient, the tendency to wire clavicles unnecessarily was also observed.

2. The tendency to overimmobilization was rather general, and it was emphasized in all hospitals that fractures of the head and neck of the humerus, the head of the radius, and the pelvis, as well as march fractures, require only minimal immobilization.

3. In many patients observed early in the war, injuries of the upper extremity were treated by excessive immobilization, especially at the metacarpophalangeal joints, with resulting unnecessary stiffness and prolonged incapacity. Correctly, the hand was mobilized at the proximal palmar crease, to avoid fibrous ankylosis of the metacarpophalangeal joints.

4. At some hospitals, the toes were immobilized routinely in fractures of the leg, both dorsal and plantar surfaces being completely covered. This was entirely unnecessary and prevented desirable early motion.

5. There was some tendency to continue plaster spicas on the femur too long. Patients in traction generally were well handled, but until the end of the war, it was necessary to emphasize the wider use of this technique. Several patients were observed who had developed deformities while fractures of the femur were in traction. There was some tendency to abandon suspension traction before it had been given a fair trial and when, as in the cases just cited, it had not been applied correctly.

6. Complications occurred whenever plating or bone grafting was carried out in the face of infection or in granulating wounds. Colonel Peterson stopped this practice whenever he encountered it. In many such instances, the bone grafts loosened and became necrotic, osteomyelitis developed, large areas of bone were exposed, and persistent purulent drainage followed. Even if some patients recovered smoothly when these practices were employed, the recovery of others was retarded, and there was loss of time and delayed convalescence. It is unfortunate that lack of time and difficulties with records, commented upon elsewhere, prevented the adoption of the consultant's suggestion that all patients in whom this technique was used be followed closely and be analyzed critically at the end of 6 months after operation.

7. Special individual techniques were not encouraged. At one hospital, seven Vitallium cup arthroplasties of the hip were progressing satisfactorily. But cellophane arthroplasty of the knee, performed in four cases, was a failure in three, and it was not clear why it had been done in the fourth case, an instance of chronic synovitis without ankylosis, which seemed on the way to failure also.

8. External fixation by multiple pins was not a desirable technique for combat-incurred fractures, as numerous cases showed. Infection was frequent when this method was used in open wounds, and not uncommon when it was used in closed (simple) fractures. At one general hospital in which the pin technique was widely used, one "enthusiast" stated that he had never observed either infection or nonunion with it. But the cases treated by this method at a nearby station hospital revealed two severe infections, one of the elbow and the other of the lower tibia, in simple fractures treated by open reduction and pinning. Three tibias fixed by this technique at one hospital showed only moderate callus at the end of a month and were in unsatisfactory position. Two older fractures of the femur treated by multiple pinning were observed at another hospital. In one, treated by four pins in the femur and two below the knee, union was evidently occurring. In the other, the femoral fracture was reduced incompletely; the fracture of the tibia on the same side as the femoral fracture had not been immobilized; union of both fractures was incomplete; and the errors of management had been compounded by premature removal of the cast for skin grafting. One patient received from overseas with dual pin fixation was, the section chief observed, "noteworthy for the misapplication of this method."

Even when pinning was used correctly and conservatively, results were not always good. In eight cases observed at one hospital, all the pins were applied correctly, but open reduction was necessary in one case, and in another, union was found to be unsatisfactory when the pins were removed.

9. A great deal of attention was paid by the Consultant in Orthopedic Surgery, on his hospital visits, to surgery of the knee, the importance of which justifies repetition here of material presented elsewhere (p. 645).

a. Single-skin and double-capsular incisions were recommended and demonstrated. The split-patellar incision was not considered satisfactory, nor was it considered justified for simple arthrotomy.

b. At one hospital, if exploration did not reveal a pathologic process in it, the cartilage was not removed. The consultant pointed out that careful exploration through a posterior capsular incision was required to identify posterior tears of a cartilage that were not apparent anteriorly.

c. Parapatellar incisions, with 10 days in plaster immobilization, gave excellent results as observed in some hospitals, though the consultant himself did not regard this technique as the procedure of choice. He favored early ambulation and rehabilitation exercises.

d. The postoperative care so essential after knee surgery was discussed by the consultant in every hospital that he visited. Poor results frequently could be explained by careless postoperative management, which resulted in effusion and weak and atrophic thigh muscles. Intensive quadriceps exercises made the difference between prompt recovery and prolonged morbidity.

e. It was not always easy to strike the proper balance in elective surgery on the knee. Delay in operating for meniscus injuries that clearly could not be corrected in any other way was probably an overreaction to the arthrotomies performed not wisely, and much too frequently, earlier in the war. The long-established principle of meniscectomy for internal derangements of the knee had fallen unjustly into disfavor. Fracture or dislocation of a meniscus was a very common injury among military personnel, and when surgery was indicated, it should have been performed promptly. As an illustration, there was no justification for delaying surgery for loose bodies in the knee in an officer with 18 months' service or for separating him from the service for disability.

10. Wounds complicated by osteomyelitis were dressed too frequently. Immobilization and infrequent dressings were preferable.

11. The incorporation of an os calcis clamp in plaster was not a sound method.

12. Long casts were not always used in fractures of the tibia and fibula. They were advised until union was firm.

13. Results were good when early ambulation and early joint mobilization were used with discretion but poor when they were used indiscriminately.

14. Several patients were treated by sequestrectomy with immediate closure of the wound. Even with penicillin, this procedure was contrary to *sound surgical principles.*

15. Several forearms in which it was thought rotation might be lost were immobilized in complete supination when the mid position was preferable.

16. Small, multiple bone grafts were sometimes used on long bones when larger grafts would have been preferable.

17. Whenever splints that did not conform with good Army practice were used, it was recommended that they be replaced. Some patients in walking casts had more than the optimum amount of knee flexion. Minimum flexion was recommended.

18. Whenever optimum results had not been achieved with skin grafts, it was recommended that the patients be treated on the plastic surgery section. The dermatome graft was not used often enough in these cases, and defects were sometimes apparent in the donor sites because the grafts had been too thick.

19. Several patients with severe traumatic arthritis of the ankle, with extreme pain and loss of function, had been managed conservatively for too long a period. Prompt arthrodesis was indicated in all such cases.

20. Skin sloughs and infection followed some arthroplasties of the elbow. It was suggested that improvement of motion could be achieved better in many instances by resection of bone without the interposition of fascia.

A number of special cases carry their own lessons and need little comment:

1. Skin traction was not always used wisely. One patient with a fracture of the femoral neck had been kept in it for 5 months, with resulting nonunion. The femoral head was viable, however, and intertrochanteric osteotomy was done. Examination 5 months later showed persistent nonunion and some necrosis of the head. It was thought that fusion would be required.

2. A patient with a compound fracture of the femur was admitted to a general hospital 12 days after the fracture had been plated through an unhealed wound, contrary to sound surgical principles. One month after the operation, the bone was exposed and purulent drainage was present.

3. In four of six grafts of the femur, the grafts had fractured several months after operation, while the patients were still in double spicas. The grafts were superficial, and when union did not occur within the expected period, external pinning was used in three cases. This was a highly questionable procedure, particularly in view of the several other patients on the same ward who were waiting for regrafting after removal of pins from their fractures.

4. A patient with a fracture of the femur treated by manipulation of the knee 14 days before the consultant's visit had sustained an avulsion of the tibial tubercle which required surgical repair. At this time, skeletal traction was in situ on the patella.

5. A patient with a severe subtrochanteric fracture presented considerable angulation during healing. Indications for adequate immobilization and traction in such cases were discussed with the responsible surgeon.

6. A patient with a fracture of the lower femur involving the knee was treated in traction in a station hospital and transferred to a general hospital in plaster a month later. When he was observed, 2 weeks after his arrival, he was still in a cast to the upper thigh. Immediate suspension traction was advised.

7. A femoral fracture, first fixed with screws, was treated with multiple pins after refracture. One of the pins, which were jointed, broke, and infection of the bone followed. Six months later, when the pinhole seemed healed, the femur was grafted and plated. The infection that followed was attributed to latent infection along the pin track.

8. Three transverse fractures of the femur were observed at one hospital, all with inadequate fixation. In two cases, only two screws each had been used. In the third, also fixed with only two screws, neither of the screws engaged both fragments. In another case, at the same hospital, the only fixation was insertion of the cortex of one fragment into the medulla of the other. Angulation had occurred in the process of correction by wedging.

9. A patient with bilateral dislocations of the hip and complete sciatic paralysis had spent 5 months overseas in three general hospitals, in one

of which he had spent 3 months. But for some unexplained reason his condition had been diagnosed as partial paraplegia, and the dislocations were not recognized until he had reached a general hospital in the Zone of Interior. The initial roentgenograms showed absence of the lesser trochanters due to rotation, widening of the space between the upper ends of the femur, and loss of joint space on one side. Apparently the femoral head on each side had dislocated posteriorly and become so closely superimposed over the acetabulum that the diagnosis had been missed. In the Zone of Interior, films showed marked posterior superior dislocation, with bone production. One side was reduced surgically, after which bilateral traction was applied. The plan was to reduce the other side surgically when the patient's condition permitted another operation. Vitallium cup arthroplasty was also being considered. Obviously, the prognosis for any useful motion in the hips was poor.

10. Spinal fusions were done for tuberculosis, spondylolisthesis, and old fractures when they were line of duty; that is, when there was a clear-cut history of aggravation in service. In one instance, in which bilateral sacroiliac fusion had been done, the diagnosis of tuberculosis was considered somewhat questionable. One patient had a painful nonunion of the odontoid, in good position, which had been treated by fusion from the occiput to the sixth cervical vertebra. The operation was regarded as unnecessarily extensive. This man was being considered for full military duty, but evidently was unfit for it. Another line-of-duty patient with posttraumatic arthritis of the lower cervical spine was being considered for a disability discharge. It was recommended that a fusion operation be done on him.

11. Two patients with nonunion of the medial malleolus were operated on and fixed without bone grafting, which is the accepted technique in such conditions and which seemed likely to be required eventually in both cases.

12. The wisdom of some operations performed with the idea of making patients fit for overseas duty was decidedly open to question. At one hospital, two operations were performed for cysts of the lower tibia; bone grafts were necessary after the excision. At another hospital, two soldiers had been cleared for overseas service though both of them repeatedly had attended the clinic, one over a 2-month period and the other over a 9-month period, for persistent locking of the knee. A patient observed at still another general hospital had been operated on 6 months earlier at a station hospital for a bone cyst in the posterolateral, proximal third of the tibia. The tibia was opened "anteromedially" below the level of the lesion and packed. Why such an operation was done was not explained on the record, but a postoperative roentgenogram showed that, in addition to the lesion just described, the patient had a bone defect and a sinus.

The error in some of these cases was not only the performance of surgery in EPTI lesions in which the patient's future value to the Army was doubtful, but also the induction of men with such lesions. A patient

at Halloran General Hospital, for instance, under treatment 2 months after induction, had a clear-cut history of chronic osteomyelitis and confirmatory scars of previous surgery for this condition.

The problem of management of preinduction defects is discussed in detail under that heading (p. 93).

Overall Evaluation of Therapy

The errors, undesirable techniques, and other practices that produced less than optimum results, particularly early in the war, make clear why the supervisory functions of the orthopedic consultants were so important. Some of the practices described simply represented individual civilian techniques carried over into the Army, where, for the reasons already stated (p. 37), military considerations took priority. Most of the errors, however, reflected the lack of training and experience, both professional and military, and consequently the immature judgment, of medical officers who had been precipitated into orthopedic responsibilities for which they were not yet fully equipped. Tours of inspection by the service command consultants and by the Consultant in Orthopedic Surgery, of the Surgeon General's Office, discouraged or forbade practices inconsistent with military requirements or with good surgery.

It is most important to realize that, though the list of errors and unwise practices covers a wide variety of clinical conditions, numerically it represents only a fractional proportion of the many thousands of orthopedic casualties cared for in Zone of Interior hospitals during World War II. For every patient poorly handled, there were many hundreds cared for correctly and even brilliantly. Colonel Peterson mentioned many such cases in his official reports: multiple fractures of the arm very well handled at Brooke General Hospital; an operation for arthrodesis of the foot at Fitzsimons General Hospital that was "an excellent demonstration of thorough, careful surgery and equally good teaching"; the sequence of early sequestrectomy and skin grafting followed by bone grafting in compound fractures with large defects complicated by osteomyelitis; the early skin grafting that was so much better than permitting chronic skin ulceration to continue indefinitely; and the generally excellent management of simple and compound fractures. This is the true picture of orthopedic surgery in Zone of Interior hospitals in World War II.

THE ARMY AIR FORCES MEDICAL SERVICE

Development

During World War II, the Army Air Forces, as the name implies, were an integral part of the U.S. Army. This held true of its medical de-

partment as well as of its other components. Practically, however, the AAF Medical Department operated, for the most part, as an autonomous organization. For this reason, it is convenient to describe its activities separately from those of the Army Medical Department (*96–100*).

In March 1942, the Air Surgeon was authorized by the War Department to recruit civilian physicians for the AAF medical services. Response was good, and by the end of this year, almost 8,000 physicians were in service and were staffing AAF hospitals and clinics and acting as flight surgeons (*97*). Of this number, about 2,500 were classified as qualified in various specialties and about 100 of these were classified as orthopedic surgeons (MOS 3153). In this group, 27 had been certified by the American Board of Orthopaedic Surgery, Inc. Another 40 had had 2 years or more of formal training and were amply qualified to be chiefs of orthopedic sections in station or general hospitals, and the remainder had had 12 to 18 months of training in orthopedic residencies.

In September 1942, Maj. (later Col.) Alfred R. Shands, Jr., MC, became Senior Consultant in Orthopedic Surgery to the Air Surgeon. On 1 June 1944, he also became Chief of the Surgical Branch, Professional Division, Office of the Air Surgeon. He exercised the functions of both assignments until 15 October 1945.

Because of its special needs, the Army Air Forces maintained hospitals and infirmaries for the care of the sick and wounded in all its training installations and at all airfields in continental United States. Many of these units were small, with bed capacities of 150 or less, and there were many small infirmaries. The sick and injured received their initial treatment in the nearest hospital installations and were transferred to the larger, more fully staffed and equipped hospitals as soon as their condition permitted and required.

By the end of 1942, more than 150 hospital installations were under the control of the Air Surgeon, though for administrative reasons, their direct supervision was assigned to the surgeons of the 12 AAF commands which these hospitals served. Several of the larger commands were subdivided further into areas or districts, with a surgeon in charge of the medical activities of each of these. By the end of 1943, there were 237 AAF hospitals and 144 dispensaries.

The Consultant System

In December 1942, Major Shands visited some 20 AAF hospitals in the Eastern, Southern, and Southwestern States. At the conclusion of his tour, he recommended to the Air Surgeon that an Army Air Forces orthopedic consultant system be set up, so that all AAF station hospitals in continental United States which had more than 50 beds might have orthopedic surgeons promptly available for consultation as the need arose. At

this time, about two-thirds of these hospitals had no orthopedic surgeons on their staffs.

Although the Air Surgeon was receptive to this suggestion, an area Air Forces consultant system was not set up until December 1943. Then, 60 qualified orthopedic surgeons were designated as area consultants, and their services were made available to all AAF hospitals and dispensaries in their areas.

This system operated very effectively until June 1944, when the War Department established regional hospitals, 30 of them in the Army Air Forces (*66*). Each regional hospital had a number of satellite hospitals, and the chief of the orthopedic section in one regional hospital served as consultant to them and visited them in turn, usually on a regular schedule.

Army Air Forces hospitals were visited also by the surgical and orthopedic consultants in the Army Service Forces. Because of the number of these hospitals, visits to them represented a major effort. In the Fourth Service Command, for instance, within a radius of 50 miles from Finney General Hospital, Thomasville, Ga., were five or six small station hospitals, each completely equipped and staffed for the patient load it was called upon to carry. There were also large AAF station hospitals at Keesler Field, Biloxi, Miss.; Gulfport Army Air Field, Gulfport, Miss.; and Maxwell Field, Montgomery, Ala.

Although they operated in a semiautonomous fashion, AAF medical installations officially were under Army control, and visits of inspection to them were within the range of responsibility of the Army Service Forces orthopedic consultants. It became increasingly evident, however, at least in some service commands, that these visits were not welcome. The probable reason, as Colonel Cleveland pointed out in one of his official reports, was that the consultants could not avoid calling attention to the fact, really self-evident, that there were too many small AAF hospitals and too much overstaffing in respect to medical, nursing, and other personnel for the patient load as compared with the comparable staffing for the patient load in Army Service Forces hospitals. The situation finally became so strained that, in some commands, AAF hospitals were visited by ASF orthopedic consultants only on specific invitation.

Operational Policies

In Army Air Forces station hospitals, orthopedic surgery was under general surgery, but had its own chief of section and staff. When the number of patients justified it, there were separate orthopedic wards, with physical therapy frequently a part of the section.

If facilities and personnel were adequate, elective surgery was permitted at AAF station hospitals, at all of which medical and surgical facilities had to be maintained to handle accidental and other injuries promptly and efficiently. Patients whose treatment was begun at station hospitals

were transferred to general hospitals as soon as they were transportable if it was thought that hospitalization would be necessary for more than 90 days.

Workload

The volume and character of orthopedic work in each AAF hospital depended chiefly upon whether or not a qualified orthopedic surgeon was on the staff and, in addition, upon the interest and enthusiasm of the medical officers in charge of the service. In a survey made in 1943 by Colonel Shands for the Air Surgeon, which covered 20 station hospitals and 8,400 patients, he found 937 patients on orthopedic wards (*98*). About 15 percent of all orthopedic dispensary patients were being hospitalized for treatment. Some of them had fresh injuries, some were being reconditioned, and some were awaiting action of disposition boards.

All conditions affecting the locomotor system were handled on orthopedic surgery sections, including fractures and other injuries, infections, and bone tumors. In an analysis of 691 orthopedic patients being cared for in hospitals and dispensaries serving some 25,000 troops, which were visited by Colonel Shands in March and April 1943, fractures and dislocations, affections of the low back, foot disturbances, and internal derangements of the knee constituted about 80 percent of the conditions encountered. At this time, there were no combat casualties in these hospitals, and more than half of the conditions encountered had existed prior to induction.

When standards for physical fitness were lowered in the spring of 1942, the policy was adopted by most draft boards and induction centers of taking any men able to hold jobs in civilian life, on the reasoning that they would be equally capable, regardless of any physical disabilities they might have, of performing equally useful service in the Army. As the result of this liberal policy, many men were inducted who were severely crippled and entirely unfit for ordinary military service and who promptly filled the dispensaries and wards of all orthopedic sections. Their diagnoses included almost all that could be found in an orthopedic diagnostic file. Some training centers organized special squadrons for these physically handicapped inductees and planned their basic training so that they could remain in service. Many of them, placed on limited service, became useful soldiers. The men who were not so segregated and trained promptly broke down under the stresses of training and had to be recommended for disability discharges.

Conferences

Administrative conferences.—In March 1943, Colonel Shands and four AAF area consultants met in Washington to discuss problems that had

arisen in AAF hospitals. After planned visits to 58 of the larger hospitals, the same group met a second time and came to the conclusion that the following problems were of special importance:

1. A lack of uniformity was observed in the organization of surgical services in various hospitals. It was recommended that each surgical service be divided into seven specialty sections, one of which should be combined orthopedic surgery and physical therapy. Anesthesiology should be a separate specialty, and the anesthesiologist should be in charge of the operating theater.

2. There was a wide variance in surgical records, especially in respect to operative notes and descriptions of complications. Although the hospitals, for the most part, were not very busy at this time (March 1943), someone had started the use of short history forms. It was recommended that this practice be discontinued at once.

3. Specimens from surgery were not sent to the laboratory routinely, and the forms for laboratory reports differed from hospital to hospital. A recommended form was sent to all surgical consultants.

4. Surgical accidents were being reported only through channels, and it was sometimes weeks before the consultants learned of them. It was recommended that, thereafter, every such accident be reported immediately to the appropriate consultants, as well as through channels, so that any necessary corrective action could be taken immediately.

5. It was found that, in some locations, the post surgeon was interfering with the operation of hospital surgical services. It was recommended that, in these circumstances, the surgeon be transferred.

6. The new regional hospital system called for a new system of reporting. It was recommended that, thereafter, regular reports concerning the care of patients be sent from satellite hospitals to regional hospitals and that area orthopedic consultants receive reports from regional hospitals based on the reports they had received from the satellite hospitals.

Professional conferences.—After his visits to AAF hospitals in the spring of 1943, Colonel Shands suggested to the Air Surgeon that regional conferences would prove a valuable means of disseminating information and providing instruction for medical officers in the various areas. The suggestion was accepted, and the conferences were planned at a meeting of the command surgeons of the Army Air Forces in the Office of the Air Surgeon in August 1943 (*99, 100*).

It was decided that a 2-day conference be held in each of the AAF regional commands, at hospitals selected (1) because their orthopedic services were well run and (2) because they were so located as to permit the attendance of the largest possible numbers of officers with the least amount of travel. Orders were issued, directing medical officers responsible for fractures and orthopedic surgery in AAF hospitals to attend the most convenient conference. At the same time, The Surgeon General of the Army and the surgeons of each of the nine service commands of the Army were invited to send representatives from their general hospitals to the conferences most convenient to them, so that the orthopedic problems of the Army and the Army Air Forces could be discussed together. The orthopedic surgeon at each of the conference sites selected was given a suggested program listing orthopedic problems relating to station hospitals and was also given a list of the AAF, ASF, and civilian orthopedic surgeons in his command who might be secured as speakers.

The first of the 12 conferences planned was held on 18 October 1943,

and the other 11 were held within the next 6 weeks. The total registered attendance was 1,460 (1,194 from the Army Air Forces, 145 from Army Service Forces installations, 25 from the Navy, and the remainder from civilian physicians). The registrants represented 228 of 244 AAF hospitals, 31 ASF general hospitals, 39 ASF station hospitals, and six naval hospitals. Of the 196 formal papers presented, 128 were from the AAF, 43 from the ASF, one from the Navy, and 24 were presented by civilian orthopedic surgeons. The average attendance at each conference was 122, and an average of 16 papers was presented at each. The conferences evoked great interest and enthusiasm, judging by the vigorous discussions conducted during them and the comments received later about them.

The subjects discussed included fractures, splinting, and transportation (12 papers); compound fractures and dislocations (102 papers); physical therapy and rehabilitation (19 papers); and burns (12 papers). The remaining papers covered a range of subjects from amputations to bone metabolism. It is notable, in view of the importance these subjects later assumed that, when these conferences were held, in the fall of 1943, only two papers dealt with penicillin and only one dealt with bone grafts and one with hand infections.

The 119 papers handed in after the conferences were carefully analyzed by Colonel Shands and were summarized for publication (*99, 100*) on the basis of (1) new and original ideas that seemed worthy of consideration; (2) old ideas on important subjects that were presented in a fresh and instructive manner; (3) controversial subjects; and (4) statistics on incidence, procedures, and end results.

One point stressed at all of these conferences was that, in rendering medical service to large numbers of patients, the best results were secured by standardization of procedures. Operations that required special skills and that were successful in the hands of only a few surgeons had no place in military surgery. To meet the challenge that lay ahead, when combat casualties would be received in increasingly large numbers, it was necessary to use procedures that were as simple as possible and that would be successful in the hands of inexperienced, as well as of experienced, orthopedic surgeons.

Physical Therapy and Reconditioning

Station hospitals in the Army Air Forces system made every effort to complete the rehabilitation of their patients and to return them to full duty. Results were particularly good when physical therapy units were associated with the orthopedic surgery sections.

Without the aid of orthopedic surgeons, the convalescent hospitals in the AAF system, in which reconditioning chiefly was carried out, could not have been established and operated. In World War II, there were very few physicians trained as physiatrists. So far as is known, only two AAF hos-

pitals had such medical officers on their staffs, Maj. Murray B. Ferderber, MC, at Westover Field, Mass., and Capt. Samuel Sherman, MC, at Keesler Field. Dr. Howard A. Rusk acted as adviser and consultant in rehabilitation in the office of the Air Surgeon. During the war, many general practitioners in the service were trained in techniques of rehabilitation and rendered excellent service.

Clinics

The clinic at Keesler Air Force Base may be taken as typical of other large outpatient clinics operated in both the Army Air Forces and the Army Ground Forces establishments. It was operated originally for 2 half days, and later for 5 half days, each week. In addition, a daily 2-hour clinic was operated for AAF dependents. The hospital at this base had 2,200 beds.

The clinics were conducted in a building originally intended for American National Red Cross and nurses' recreation purposes and later found not to be needed for them. It was set up with a large waiting room, an examining room divided into three cubicles, a reception and record office, an office for the chief of the orthopedic service, and an office for his secretary. The main clinic space consisted of a large room provided with examining tables, an Albee-Compere fracture table, and other standard equipment. Two tables were available for making hyperextension body casts for fractures of the spine, and there was ample storage space for plaster, felt, sheet wadding, and other material. The elevated podium for examining feet and legs had been constructed at the hospital, as had the tables for body casts.

The orthopedic clinic at Keesler Field handled an average of 250 military patients and 120 civilian patients a week. At least one orthopedic officer was on duty in the clinic at all times. Other personnel included a staff sergeant in charge, a secretary (a dependent), one or two chiropodists with one assistant, two enlisted men for the castrooms, and a bracemaker with two assistants. Nurses and other female military personnel attended the clinic at the same time adult females were treated, which made it possible for the nurses to provide the necessary coverage for them.

Because all military personnel had to march, drill, and stand for long hours on hard ground, the foot problem was acute, even in the Army Air Forces, and required so much time and effort that eventually special clinics were set up two mornings a week for foot complaints. A shoe alteration shop connected with the clinic had enough space to make casts of feet, molds from casts, and arch supports, made from the molds, of leather, rubber, and spring steel. It was thus possible to provide for each soldier the precise type of metatarsal support his individual difficulty required.

The dependents' clinics, which were an AAF responsibility, handled many patients and observed many orthopedic conditions. In children, fractures were frequent, as they always are. Flat foot problems were numerous. Also treated were genu valgum and genu varum, dysplasia of the hips,

clubfoot of the equinocavovarus type and the simpler metatarsus varus type, hydrocephalus with deformity of the extremities, arthrogryposis, multiplex congenita, spina bifida with meningocele, scoliosis, and bone tumors. Acute poliomyelitis was observed sometimes in mothers as well as in children.

Conditions observed in adult dependents included the painful feet that come from wearing stylish shoes; osteomyelitis; pes planus and other congenital deformities; postural backaches; and injuries, including fractures of the femur, which often were severe, and trimalleolar fractures of the ankles. The variety of conditions observed in both adults and children over such a short period exceeded those likely to be encountered in an individual civilian practice.

Braceshops

Only a small number of AAF station hospitals had attached braceshops. Among them was the hospital at Keesler Field. Here, the shop, with an adjoining fitting room, was housed in the rear of the field, in a small building originally intended to house a forge unit. An old cavalry forge, of World War I vintage, was secured, and served admirably to temper steel for arch supports and other purposes. Equipment, which was bolted to the concrete floor when necessary, consisted, among other items, of a lathe, rotary and upright band saws, a large anvil with the necessary sledge hammers, a riveting and a rivetsetting machine, a machine for cutting threads in steel in the preparation of joints, and sewing machines. All of this equipment was secured from Air Forces Supply and was not the equipment supplied to Army Service Forces braceshops (p. 60). Metal and leather were obtained through the Air Metal Supply depot and were cut as needed.

Two enlisted men were assigned to the arch support shop, both, preferably, chiropodists. The bracemaker was a former blacksmith; he had two enlisted men as assistants. He was most ingenious and intelligent, and under the direction of the chief of the orthopedic section, Capt. (later Maj.) Milton C. Cobey, MC, he learned to turn out excellent braces.

In the Mississippi climate, which was hot and humid for many months of the year, plaster-of-paris casts cracked if they were worn for any length of time. In 1944, a plastic unit was set up to fabricate plastic braces, including cockup splints for wrists, arch supports, shoulder spicas, body jackets, neck collars, and long leg splints. Plastic was used also as a substitute for steel in some braces.

As the plastic process was perfected, information about it was disseminated to various station hospitals, including those to which Captain Cobey served as Regional Consultant in Orthopedic Surgery. On several occasions, arch supports and braces made at this plastic shop were requested by, and supplied to, overseas installations.

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Part II

EARLY MILITARY PROBLEMS

CHAPTER III

Diseases and Conditions Existing Prior to Induction

Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

HISTORICAL NOTE

Promulgations of the Medical Department of the U.S. Army in World War I are clear evidence that EPTI (existing prior to induction) conditions and their management furnished the same difficulties in that war as they did in World War II (*1*). On 25 June 1918, a circular memorandum from the Surgeon General's Office cited "a recent cablegram from General Pershing" to the effect that he wanted no more men with "flat feet, weak backs, and lack of muscular development" sent overseas until they had received special training "to restore them to normal." At the time of his message, some 600 men from the 26th Division were "receiving reconstruction work" in a special training camp. Men in these categories, in General Pershing's opinion, should be segregated during training in the United States.

The memorandum, after citing General Pershing's complaint, made the following points:

1. Obviously, sufficient care had not been taken in the detection and elimination of men with orthopedic problems, and necessary steps should be taken to correct the situation.
2. Men with the orthopedic defects in question should be eliminated at the induction examination. Since orthopedic specialists were then represented on all induction boards, very few applicants with these defects should be passed for general military service.
3. Men who had been accepted and assigned to duty and who later developed orthopedic defects should be promptly transferred to development battalions for special training.[1] Observance of this regulation would leave few men with such defects in organizations when the order came for transfer from one camp to another or from a camp to a port of embarkation.

Earlier, on 11 March 1918, a circular letter from the Surgeon General's Office had stressed that the primary consideration in all orthopedic operations was whether or not the presenting condition had been incurred in line of duty, a consideration that was military rather than surgical. If a man had a preexisting disability, not incurred in line of duty, but was

[1] The idea of establishing special training organizations for "the reclamation of incipient defects" in mobilization camps was first suggested by an orthopedic surgeon at Camp Kearny, Calif., in November 1917. The camps were authorized in March 1918 and formally instituted in May. Fifteen were in operation when the Armistice was signed in November 1918. These development battalions served their purpose very well, in large measure because of the impetus of orthopedic surgeons (*2*).

operated on for it, the condition immediately became LOD (line of duty), and the patient could use it to avoid duty or obtain a discharge. Also, the element of doubt always remained whether or not he really benefited by the procedure. The operation might have benefited him, but it worked an injustice to the Government. It was, therefore, directed that, in the future, orthopedic surgeons would not operate for hallux valgus, internal derangements of the knee joint, un-united and mal-united fractures, spurs on the os calcis, or similar EPTI conditions.

In another circular letter from the Surgeon General's Office, dated 22 July 1918, arrangements were made for tracing the military value of operations performed for hallux valgus or bunion, hammer toe, and internal derangements of the knee joint.

GENERAL CONSIDERATIONS OF INDUCTION IN WORLD WAR II

Paragraph VII, section 9.(b) of U.S. Public Law 144, 78th Congress, passed in July 1943, provided that "* * * every person employed in the active military or naval service shall be taken to have been in sound condition when examined, accepted, and enrolled for service except as to defects, infirmities, or disorders noted at time of the examination, acceptance, and enrollment, or where clear and unmistakable evidence demonstrates that the injury or disease existed prior to acceptance and enrollment and was not aggravated by such active military or naval service" (*3*).

Mobilization Regulations No. 1–5, "Standards of Physical Examination During Those Mobilizations for Which Selective Service Is Planned," were issued on 5 December 1932 (*4*). The Selective Service standards published at the same time were identical with the mobilization regulations, even to the numbering and lettering of the paragraphs and sections, to simplify procedures if mobilization should become necessary. A number of changes were made subsequently, particularly in MR (Mobilization Regulations) No. 1–9, issued on 31 August 1940 (*5*), but it is remarkable how many of the basic concepts established in 1932 and retained in 1940 were still in effect at the end of hostilities in 1945, after they had been put to the test of experience.

Categories of evaluation for induction included:

1. Unconditional acceptance.
2. A status between unconditional acceptance and outright rejection, in which the candidate was qualified for limited and special service; this category was discontinued in July 1943 (*6*).
3. Total and permanent disqualification for service.

There were further breakdowns of these categories as the war progressed, but the major classifications remained as listed throughout hostilities.

Regulations concerning certain orthopedic conditions underwent

changes as the war progressed. At first, for instance, Selective Service registrants with a history of osteomyelitis were accepted if the disease had not been active within the past 5 years. In the final revision of standards, osteomyelitis of any bone, or a substantiated history of osteomyelitis at any time, was a cause for rejection.

Rheumatic fever went through the same process of evolution. Originally, acute rheumatic fever, recurrent attacks thereof, chronic articular rheumatism, and chronic arthritis were totally disqualifying defects if the story of recurrence could be verified and if malingering could be excluded. In April 1944, a verified history of either a single attack or recurrent attacks was made a cause for rejection.

Many soldiers with old poliomyelitis were inducted, in spite of residual weakness and deformities. Some of them rendered good service. Men who had had foot stabilization operations many years earlier marched and drilled without fatigue or discomfort. One man with a completely flail left leg had learned, through the years, how to stabilize the knee in walking. He could not carry out drilling, hikes, and certain exercises, but he could, and did, do a great deal that was required of him.[2]

The Professional Service Division, Surgeon General's Office, was responsible originally for administration and guidance in physical standards (*8*). Later, this responsibility was turned over to the Preventive Medicine Division of the same office, which farmed out the responsibilities to various subdivisions. Still later, as the workload increased, all the responsibility for physical standards was concentrated into one office element of the Preventive Medicine Division. In all, there were five reorganizations between 1938–39 and July 1943.

Increasing amounts of time were required as the war progressed to be certain that individuals, especially those in the Reserve, with preexisting disabilities and chronic progressive conditions were not placed on active duty and shortly afterward found unfit for active service, a development which permitted them to retire with benefits to which their brief service really did not entitle them.

Under the 1932 regulations (*4*), local boards had the original jurisdiction for acceptance or rejection of draftees, subject to review on appeal to boards of appeal. When the diagnosis was doubtful, the draftee was referred to a medical advisory board, whose judgments were useful particularly when evaluation for limited or special service was involved. The final decision for acceptance or rejection rested with the examining physicians at whatever station the draftee was sent to on induction.

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[2] Readers who are interested in the evolution of these and other orthopedic conditions as causes for rejection or limited service as the war progressed will find the full information in "Physical Examination of Selective Service Registrants," Special Monograph No. 15, volume 1 TEXT, 1947 (*7*).

RESULTS OF PHYSICAL EXAMINATIONS

Examinations at the induction centers, on the whole, were efficient in eliminating selectees totally unfit for the rigors of military service. The liberal use of roentgenologic examinations at these centers at first glance might seem wasteful and extravagant, but, as a matter of fact, this was a surprisingly rewarding method. An entirely unexpected amount of pathologic change, particularly orthopedic states, was thus revealed, and it was possible, without undue delay, to evaluate the draftee at once and either eliminate him as incapable of military service or classify him for limited service.

In spite, however, of the general efficiency of examinations at the induction centers, a considerable number of soldiers were encountered in clinics and hospital wards who had been inducted with really severe structural defects. Why some of them ever were considered for induction was not possible to say. In March 1944, for instance, a patient was observed at Halloran General Hospital, Staten Island, N.Y., with chronic osteomyelitis of the femur; he recently had been inducted, in spite of a clear-cut history and confirmatory deformity and scars. In June 1944, in the outpatient clinic of the regional hospital at Fort Meade, Md., two patients were examined who had been cleared for overseas combat duty in spite of stories of persistent locking of the knee joint for the past several months. By strict interpretation of WD (War Department) Circular No. 164, dated 26 April 1944 (*9*), this action was permissible, but neither of these men would have been of any help in an active theater of operations; they merely would have occupied hospital space and return shipping space.

Many draftees with orthopedic defects who had evaded the induction net presented serious problems of redistribution to the dispensary surgeon, the classification board, and the unit commander. The folly of sending overseas men who were intended for combat duty and were unfit for it was evident at Ashburn General Hospital, McKinney, Tex., in December 1943, when Col. Leonard T. Peterson, MC, reported that about 25 percent of the patients on the orthopedic section had complaints referable to feet and back and had been returned from overseas as combined orthopedic-psychoneurotic problems in disposition.

Earlier that year, when he was commanding officer of the 14th General Hospital, Camp Livingston, La., which was then preparing to go overseas, Colonel Peterson had commented in his official diary that he was impressed repeatedly by the sheer waste in time, training, effort, and expense of inducting men for service in a unit of this kind when they were totally unfit for it in any respect. They simply interfered with the efficient training of qualified men, and their disposition required a great deal of time that could have been expended more profitably otherwise. At this time, 95 men, about 25 percent of the total hospital strength, were about to be discharged or transferred for reasons of age or mental or physical disability.

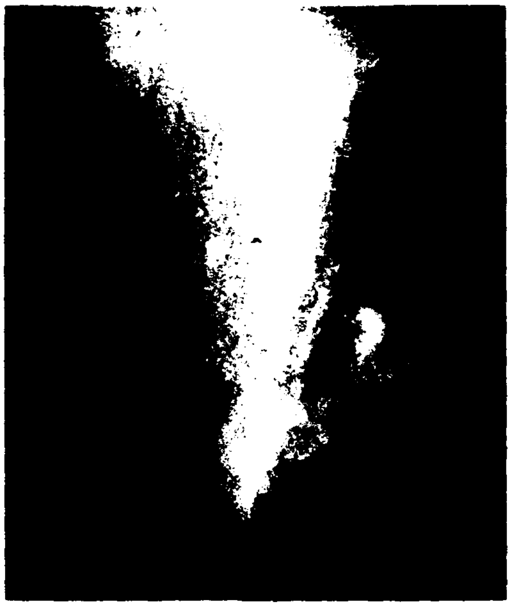

FIGURE 3.—Anteroposterior roentgenogram showing osteochondroma of upper end of tibia, which has eroded almost through fibula near peroneal nerve. Removal of the tumor would have endangered the nerve and might have required resection of the upper end of the fibula. It was producing annoying and disabling symptoms, and the soldier was discharged after 4 months of service. (Figures 3–13 were supplied by Maj. Louis W. Breck, MC, from material on orthopedic problems in troop training, based on his experiences as Chief of the Orthopedic Section, Regional Hospital, Camp Swift, Tex.)

It was the function of the orthopedic surgeons assigned to training camps to determine, at the 6-week and 12-week examinations, as well as at the final physical examination (POR, Preparation for Overseas Movement of Individuals), that the trainee was without musculoskeletal defects or, if such defects were present, what their degree was.[3] After divisions were activated and sent into combat, the Infantry Replacement Training Center became the chief source of ground force contributions to the war effort. The orthopedic surgeon played an important part in preparing, processing, and furnishing replacements for both enlisted and commissioned personnel to

[3] At some hospitals, the processing examinations were held at night, with dispensary surgeons and post hospital personnel present and with other specialists, particularly neuropsychiatrists, participating in the decisions. These conferences proved a useful method of teaching inexperienced dispensary surgeons, by actual example and demonstration, the proper relation of complaints to objective findings.

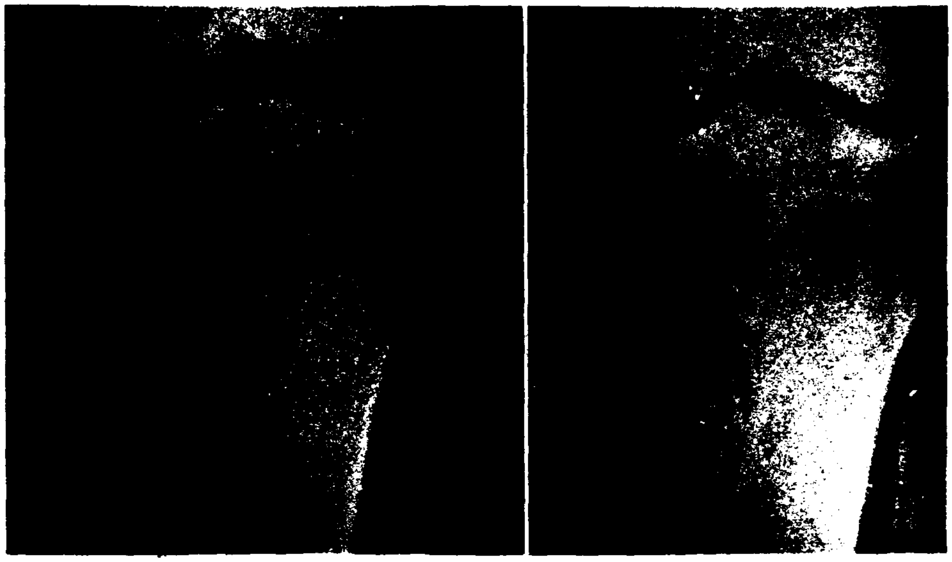

FIGURE 4.—Osteochondroma of tibia. (Left) Anteroposterior roentgenogram, showing tumor in upper medial aspect of tibia. (Right) Same, 5 months after operation. The tumor has been removed completely and no tendency to new bone formation is evident to date. Because of its location, this tumor was traumatized repeatedly during training and was painful and disabling. After operation, the patient returned to full duty. This case illustrates the possibilities of elective surgery for EPTI disabilities in properly selected patients.

the combat elements of the Army, and in carrying out these tasks expeditiously.

Because of the excellent diagnostic facilities available at station and regional hospitals, accurate diagnoses could be arrived at in all orthopedic cases except those in which biopsy was necessary. When biopsy was necessary, chiefly in bone tumors (figs. 3 and 4), the candidates were sent to general hospitals.

Affections of the foot, back, and knee are discussed in detail later, under the appropriate headings, but a word should be said about them here. Such conditions often furnish problems in civilian life. The tremendous incidence of these complaints during training in World War II baffled many young dispensary medical officers. This situation, Maj. Patrick C. Doran, MC, noted in a report on training injuries (p. 227), should be brought to the attention of medical educators. It was his experience that a recent graduate of any medical school was a most uncommon individual if, without special training in the Army, he knew how to conduct a competent examination of the foot, the back, or the knee.

Much of the initial confusion concerning induction of men with orthopedic disabilities was clarified by strict adherence to the standards specified in MR 1–9 (*5*), by the methods of examination developed, and by correct appraisal of roentgenologic findings. Objective interpretation of

physical and roentgenologic findings by orthopedic medical officers helped the dispensary surgeons keep a high effective rate of trainees on full duty in the face of the many foot, knee, and back complaints on all sick calls. From the purely military standpoint, the maintenance of troops on full duty was the primary function of the Army Medical Corps; humanitarian goals were second. Rehabilitation of the man with preexisting disabilities was accomplished so seldom by surgical methods that their frequent use could not be considered as making a contribution to the fighting strength of the Army (p. 102).

INCIDENCE OF ORTHOPEDIC DEFECTS

Analysis of the data obtained on Selective Service registrants examined between November 1940 and December 1943 in continental United States showed the following prevalence of orthopedic defects (*10*):

Total defects amounted to 1,105.7, and musculoskeletal (or orthopedic) defects to 87.5, per thousand.

Between 18 and 20 years of age, total defects were 746.8, and orthopedic defects 56.8, per thousand.

Between 21 and 25 years of age, total defects were 1,035.9, and orthopedic defects 76.9, per thousand.

Between 26 and 29 years of age, total defects were 1,270.9, and orthopedic defects 97.8, per thousand.

At 30 years of age and over, total defects were 1,312.7, and orthopedic defects 113.1, per thousand.

Defects of the feet amounted to a total of 90.1 per thousand. By the age groups just listed they were, respectively 58.8, 99.5, 115.6, and 83.5 per thousand.

When the principal defects encountered in Selective Service registrants were analyzed as such, in terms of 100 percent totals, musculoskeletal defects amounted to 5.6 percent. They were exceeded only by defects of the eyes (8.7 percent) and were followed by mental disease (4.7 percent) and cardiovascular disease (4.4 percent).

SPECIAL STUDIES

In July 1943, Maj. Frederick Kellogg, MC, reported the results of physical examinations of personnel applying for commissions in a metropolitan area (*11*). The proportion of defects in 417 physicians, 555 other civilians, and 1,047 enlisted personnel and noncommissioned officers was, respectively, 24 percent, 6 percent, and 3.5 percent. In all, 84 percent of the military personnel, 72 percent of the nonmedical civilians, and 48 percent of the physicians met the physical standards for induction without qualifications. Orthopedic defects in all three groups were insignificant and accounted for no outright rejections.

A most instructive report on EPTI conditions was made in June 1944

by Maj. (later Lt. Col.) Frank J. Vokoun, MC, who served for several weeks with a rating board of the Veterans' Administration that passed on requests of disabled veterans for pensions (*12*). The majority of those applying had been separated from service on CDD (Certificate of Disability for Discharge), line-of-duty-no, sometimes almost immediately after induction because of EPTI conditions. If the preexistence of the defects could not be established, the rating board had to assume that the disability was not preexistent and award the man a pension.

Major Vokoun's observations showed that, in hundreds of the patients under review, the preinduction examination should have been more thorough. Often when the inductee admitted defects or gave a history of previous difficulties, the examining physician had failed to develop the information properly or to read the roentgenograms with sufficient care. In the cases under review were many men who had concealed their EPTI conditions from patriotic motives but who had found Army life and discipline too strenuous and were seeking a way out of it through their preexisting chronic conditions. The Army was not benefited by the induction of men with such conditions as arthritis, foot and back disabilities, and internal derangements of the knee. These conditions were all likely to be exacerbated by full military duty, and the hospital space needed for men who would be of use to the Army was occupied by patients who were of no use at all.

As the result of his observations on the rating board, Major Vokoun found that informative progress notes, particularly in neurosurgical and orthopedic cases, were essential for correct evaluation. Rating boards studied these notes assiduously, and it behooved military surgeons to keep them current. Data on the degree of recovery of function were of the greatest importance.

Major Vokoun also deplored the tendency to omit discharge summaries. No case history, in his opinion, should be passed by the hospital registrar without one. Such summaries might seem useless and boring to ward officers, but failure to supply them seriously affected the equitable adjudication of pension claims.

CERTIFICATE OF DISABILITY FOR DISCHARGE

It has already been pointed out that disabilities which had existed before induction, and which might or might not have been aggravated by service, often constituted major problems for the orthopedic surgeon whether they were encountered in training camps or elsewhere. This was true even when the conditions were minor and, in civilian practice, would have been treated on an ambulatory basis. Army organization, however, did not include outpatient or quarters status for the treatment of such disabilities. In the Army, a patient must either do full duty or be hospitalized while he could not; if hospitalization of any duration was required,

and if his disability was of the type likely to be recurrent, it was often simpler and more economical in the end to separate him from service at once.

Discharges for physical reasons were given to enlisted men under Section II, Army Regulations No. 615–360 (Certificate of Disability for Discharge) (*13*). The decision to grant such discharges rested on the findings of boards of medical officers, on which large numbers of orthopedic surgeons served, but the number of discharges granted reflected Army personnel policies more than the occurrence of physical defects and other medical considerations (*14*).

The sharp rises in discharge in August and September 1943 were traceable to WD Circular No. 161, dated 14 July 1943 (*6*), which required reexamination and discharge of limited service men who did not meet current physical or mental standards. In November 1943, WD Circular No. 293 (*15*) directed that no man be discharged for physical reasons as long as there was some position in the Army that he could fill. This policy was reiterated in WD Circular No. 164 (*9*), and the sharp decline in discharges from November 1943 through the second quarter of 1944 was a reflection of this policy. The increased number of discharges in July and August 1944 reflected the increasing number of men with overseas service who had been evacuated in recent months. Another sharp rise in September 1944 reflected a continuation of this trend; it also reflected the effect of WD Circular No. 370, dated 12 September 1944 (*16*), which provided that enlisted men in the Zone of Interior could be discharged if they did not meet minimum physical standards for induction for limited service or if appropriate positions for them were not reasonably available.

The largest single group of CDD separations up to December 1944, when the analysis just cited was published, was for neuropsychiatric disorders (39.4 percent in 1943 and 48.3 percent in 1944). Musculoskeletal conditions ranked second, accounting for 18.7 percent of all discharges in 1943 and 8.1 percent in 1944. Discharges for these causes, as well as for genitourinary, cardiovascular, and respiratory causes, were more frequent in men who had not been overseas, probably because the troops sent overseas represented higher standards of physical fitness.

TERMINAL PHYSICAL EXAMINATION

To complete the record of orthopedic responsibility for discharges from the Army, certain details concerning the terminal physical examination are added herewith.

War Department Technical Manual 8–255, dated 10 September 1945 (*17*), made the following provisions for the musculoskeletal component of the terminal physical examination on separation from military service, with roentgenologic examinations to be made in all cases in which the examiners considered them indicated.

In the joints, loss of function was the cardinal consideration in evaluating residuals of injury. Points to be investigated included:

1. Less motion than normal: ankylosis, limitation or blocking, adhesions, tendon fixation, contracted scars.
2. More motion than normal: flail joint, relaxation of ligaments, resections.
3. Weakened motion: muscle injury, injury or disease of peripheral nerves, divided or lengthened tendons, excess fatigability.
4. Pain on movement.
5. Incoordination: impaired ability to execute skilled movements.
6. Deformity, atrophy, or swelling.
7. Interference with sitting, standing, or weight-bearing.

The terminal investigation included, besides flexion and extension, other normal motions of the joints, such as supination and pronation of the forearm, and adduction, abduction, circumduction, and rotation of the shoulder and the hip. When joint motion was limited, the arcs through which it was reduced and preserved were shown graphically. Goniometry was required for accurate measurement of angular position. Anteroposterior and lateral instability of the knee was recorded with notation of frequent episodes of synovitis, displaced cartilage, tear of the lateral ligaments, and chronic joint strain.

When a history of bone or joint disease was secured, the location and extent of the involvement were recorded, with notes on the residual disability (pain, weakness, deformity, shortening). If shortening was associated with nonunion of a fracture, the length of both intact and injured extremity was recorded.

In amputations, the record included the exact level of the amputation, the length of the stump, and details of its condition.

In muscle injuries, the record covered residual weakness, fatigue, pain, incoordination, loss of tone, loss of muscle tissue, and size and location of scars. In muscular atrophy, the circumference was recorded at the same level for both the normal and the injured extremity.

In peripheral nerve injuries, the precise nature of the involvement was determined (motor, sensory, or both; complete or incomplete). The examiner was warned to remember that loss of motion in an extremity might result from conditions other than muscular paralysis, such as ankylosis, tendon injury, and contractures.

ELECTIVE SURGERY FOR EPTI DISABILITIES

In the early phases of U.S. participation in the war, as already intimated, orthopedic surgeons newly inducted from civilian practice tended to look upon EPTI (and most other) disabilities from a purely civilian standpoint, taking little or no cognizance of military considerations. They had been told that their objective was the fullest possible utilization of manpower, and it seemed to them entirely practical to perform elective surgery for at least some of these disabilities. In the Army, however, the situation was somewhat more complicated. A number of other points had to be considered:

1. The time element, that is, the occupancy of hospital beds for long periods of time, with the corresponding drain on professional and nursing manpower.
2. The possibility of recurrence of the lesions.
3. The patient's mental attitude and motivation. Both could play crucial roles in the success or failure of the procedure.
4. The difference between military and civilian criteria of success. What might

be accounted an excellent result in civilian surgery might be accounted a poor result or an absolute failure in military surgery. In military surgery, the criterion of success was the restoration of the individual to full duty, which implied strenuous training activities and later combat duty. Every soldier with a disability that might be corrected by surgery had to be evaluated on his individual status, merits, and potentials before surgery was recommended for him.

From the beginning to the end of World War II, there was never complete agreement on the interpretation of official policies concerning corrective (elective) surgery for preinduction disabilities. The almost universal tendency to perform surgery for them early in the war frequently was not justified by the end results from the military standpoint. This tendency was succeeded, later, by almost too high a degree of conservatism. In fact, service command Consultants in Orthopedic Surgery, as well as the Consultant in Orthopedic Surgery, Surgeon General's Office, occasionally called attention to unwarranted delays and hesitancies in the management of knee joint disabilities that could be corrected only by surgery. As the war progressed, a little hesitancy was felt in separating men from service on Certificate of Disability for Discharge with the recollection of the many patients in whom, earlier, this would have been a wiser procedure than the elective surgery that was carried out and that, from the military standpoint, was a failure. It was part of all consultants' functions to assist in the screening of orthopedic patients from this point of view.

Official War Department Directives

The important War Department instructions, direct or implied, for elective surgery in World War II were as follows:

27 December 1941.—War Department Circular No. 270 (*18*) provided that no man should be separated from active service because of disability unless the Government could obtain no useful service for him. In many quarters, this directive was interpreted as justification for elective surgery to correct defects.

19 July 1943.—War Department Circular No. 165 (*19*) provided that patients who required "elective surgery of a formidable type" should be transferred, as soon as they were transportable, to general hospitals, such surgery (which was not defined further) being among the functions of these hospitals.

22 November 1943.—War Department Circular No. 304 (*20*) was to the same effect.

26 April 1944.—War Department Circular No. 164 (*9*) provided for the use of manpower of enlisted men according to their physical capacity. It also, as already mentioned (p. 109), discontinued the use of the term "limited service" as applied to enlisted men. It stated specifically, however, that discontinuation of the term did not mean that men thus classified were to be discharged or that the Army would not continue to induct and use men who did not meet the full standards for general service. With certain exceptions (none of them orthopedic), no man was to be discharged for physical disability if he met the minimum standards for induction currently prescribed in MR 1-9 (*5*). Again, many orthopedic surgeons interpreted this directive as justification for elective surgery for the correction of orthopedic defects.

4 December 1945.—Section I of WD Circular No. 360 (*21*) was, for the first time, entirely specific about elective surgery for preinduction disabilities: To achieve maxi-

mum utilization of manpower, it was desirable to perform elective operations to correct preinduction and preenlistment disabilities, but selection of cases must be carried out with great care. Such surgery should be considered only for individuals with conditions which had been shown by experience to be readily correctible and correction of which would restore the patient to full military usefulness within a relatively short time. It should not be considered if it would require prolonged hospitalization or if the chances of failure were great. Among the illustrations of conditions for which operation should not be considered were internal derangements of the knee unless the crucial and lateral ligaments were intact, the thigh musculature was strong, and there were no arthritic changes. Finally, operation to correct EPTI defects should be considered only in individuals who gave particular promise of being of future value to the Army from both a mental and a physical aspect.

Circular Letters, Surgeon General's Office

30 November 1942.—Circular Letter No. 167 (*22*) instructed all medical officers to consider carefully the future value of military personnel before undertaking elective operations for preinduction disabilities. Internal derangements of the knee were singled out as one of the conditions requiring particularly careful selection.

17 November 1943.—Circular Letter No. 190 (*23*) was to the same effect, but permitted operation for internal derangements of the knee if the specifications (later) listed in WD Circular No. 360 (*21*) were met.

FOLLOWUP STUDIES ON ELECTIVE SURGICAL PROCEDURES

The limited opportunities for followup studies in World War II make the few that were carried out, and were carried out properly, of particular educational value. In this class are the followup investigations of elective surgery performed at the Fort Jackson, S.C., Station Hospital in 1942 for internal derangements of the knee and hallux valgus. Both series were studied by the same group: Lt. Col. (later Col.) Mather Cleveland, MC; Maj. (later Lt. Col.) Leon J. Willien, MC; and Major Doran. Both studies are deliberately reported in considerable detail.

Disabilities of the Knee—First Survey

Disabilities of the knee were particularly important during early training periods, when, if preexistent lesions were present, they were likely to become manifest because of the "provocative" activities required. Many previously damaged knees, deliberately or accidentally overlooked by induction boards, were reinjured, and their management furnished a considerable problem. The vagueness of WD Circular Letter No. 270 (*18*) was interpreted variously, as already mentioned, as justification for elective surgery and as a warrant for prompt separation from service of men with these disabilities.

The reports at the conference of service command consultants in Oc-

tober 1943 (*24*) on elective knee surgery were discouraging. Col. John B. Flick, MC, Consultant in Surgery, Ninth Service Command, stated that surgery for these disabilities had been discontinued in his command because of the poor results. Col. Rex L. Diveley, Senior Consultant in Orthopedic Surgery, European Theater of Operations, U.S. Army, said that, in that theater, operation on the knee was done only after he himself had examined the patient and was performed always by an orthopedic surgeon whom he designated.

At this conference, Colonel Cleveland reported the results of the followup study of elective surgery for knee disabilities carried out at Fort Jackson in 1942 (*25*).

Materials and methods.—This study was undertaken to establish some consistent policy for the management of these disabilities, based on the replies to certain specific questions:

1. Should any internal derangement of the knee joint be operated on during service in the Armed Forces?
2. If so, which type responds best to surgery?
3. What is the duty status of these soldiers after their discharge from the hospital?
4. Should a soldier with a long EPTI history of knee disability, who reinjured his knee soon after induction into service, be operated on or be reclassified for limited service without surgery?
5. Is rehabilitation successful enough, and successful in enough cases, to warrant routine surgery for disabilities of the knee?
6. Are any soldiers operated on discharged subsequently because of knee joint disability?

The answers to all of these questions were of great importance to the military surgeon in his decisions concerning management of these injuries. The functional ability of the knee after operation was far more important in military than in civilian life. No more exacting tests could be conceived of than those imposed upon the Infantry, who made up a large proportion of the Fort Jackson population. If a man could withstand the rigors of Army training—drill, calisthenics, long marches, and obstacle courses—his rehabilitation was complete in the fullest sense of the word; he was being tested far more severely than he would be in any conceivable civilian occupation.

Followup is never easy in military circumstances and is particularly difficult on a training post, where the population is constantly shifting. The first phase of the investigation at Fort Jackson was, therefore, the location of the patients selected for the study.

The second phase was the selection of objective criteria of results, based on the realization that the surgeon's opinion of the results was not necessarily that of the man himself or of his commanding officer. The criteria agreed upon were simple but conclusive: If a man could resume all his duties in his organization, it could be assumed that surgery had been justified and successful and that the disability had been treated properly.

A form letter was prepared for each patient's commanding officer and was sent to him with the request that he check the following items:

> 1. Has this soldier been able to resume all his duties? Yes No
> 2. If not, has he been reclassified or discharged on CDD because of disability?
> 3. Remarks

This type of followup questionnaire practically eliminated the opinion of the orthopedic surgeon who had performed the operation. Its success or failure was determined by the facts as supplied by the patient, his company officer, and his unit medical officer.

In addition to the questionnaire, all other possible sources of information concerning the subsequent duty status of these patients were checked, including hospital records for later admissions, to see if there was any reference to the knee; records of the Medical Reclassification Board; and consultation records of the outpatient orthopedic surgery clinics. It was disconcerting to find that some patients had been referred to the reclassification board the day after they had been discharged from the hospital, with what was thought to be an excellent result.

No attempt was made in this investigation to secure statistical data on postoperative range of motion, local swelling, atrophy of the thigh or calf, and similar findings. The result was considered satisfactory if the man could do full duty, and unsatisfactory if he had been reclassified or discharged on CDD.

Basic data.—This study was carried out on 75 soldiers who underwent 76 arthrotomies of the knee, all during 1942. During this year, 22,186 patients were admitted to the Fort Jackson Station Hospital. There was one Negro in the series; the post racial proportion was 1 : 75, which might mean that internal derangements of the knee were less common among Negroes, but the figures are too small to warrant conclusions.

The 75 patients included 25 officers, noncommissioned officers, and air cadets, and 50 enlisted privates. The distribution as to branch of service was Infantry, 33; Field Artillery, 10; Air Corps, seven; and Corps of Engineers, six. The remaining 19 men were from the Quartermaster Corps, Tank Destroyer Battalion, Cavalry, Ordnance, Sanitary Corps, Medical Battalion, and Station Complement. It should be noted that most of the patients were combat troops.

The age range in this series was from 20 to 42 years. The average was 26 years, about that of all the troops on the post. The length of service ranged from 7 days (in a man who practically stepped from the induction station into the hospital) to 4½ years, with an average of 11½ months. The right knee was affected in 40 cases, and the left, in 35.

In 12 cases, no history of trauma could be secured. In 41 cases, the injuries were considered to have been incurred in line of duty. Three men

were on limited service when they were operated on, and the remainder of the disabilities were considered EPTI. This classification was extremely important. If the man had been injured in line of duty, then it was the responsibility of the Armed Forces to rehabilitate him. If his disability had been present before induction, it was necessary to decide whether to operate on him and thus make the Government responsible for him, to reclassify him for limited duty without surgery, or to discharge him at once.

Diagnosis and indications for surgery.—These 75 patients represented about 15 percent of the men admitted to the Fort Jackson Station Hospital with knee derangements during 1942. A large number of the admissions were for sprains and contusions. Patients with suspected knee derangements were studied carefully on ward rounds, and, if the diagnosis was doubtful, they were presented for discussion at the daily staff conference. Diagnostic precision was insisted on; no diagnosis such as "loose" meniscus was tolerated. No matter how plausible the history might be, physical signs also were insisted upon for diagnosis. In order of frequency, they were atrophy of the quadriceps; tenderness at the joint margin over the involved meniscus; an increase in intra-articular fluid; palpable dipping of the joint; and blocked motion, usually at 150–160 degrees of extension. True locking of the knee was seldom observed; 50 to 75 degrees of motion almost always was present.

If the injury was fresh and responded to conservative treatment, the patient was returned to duty, with the understanding that operation might be recommended if his symptoms recurred. Surgery was avoided on officers and men with inadequate personalities, who were unlikely ever to be qualified for full combat duty and who might use surgery and its residua as a means of avoiding further military service. The decision was often a delicate one, but in wartime, psychic as well as somatic manifestations had to be considered.

Operation and postoperative course.—In eight cases, although the clinical diagnosis had been considered incontrovertible, no tear or other pathologic process was found at operation. The findings at the other 68 operations were:

Tear of meniscus	35
Tear of lateral meniscus	6
Tear of both menisci	3
Cyst of lateral meniscus	4
Cyst of medial meniscus	2
Osteochondritis (with or without loose bodies in joint or damage to intra-articular cartilage)	13
Fracture into joint with tear of medial meniscus	2
Fracture into joint without cartilaginous injury	1
Gunshot wound	1
Xanthoma	1

Surgery consisted of exploratory arthrotomy, excision of damaged menisci or damaged articular cartilage, and excision of loose bodies. Two points of technique were stressed, that the entire involved meniscus must be removed by the Bosworth technique and that a second, posterior incision must always be made in the capsule, to permit complete exploration (p. 663).

Hospital stay days after operation ranged from 20 to 223, and averaged 58. Since the men had to return to full duty immediately on discharge, a hospital stay of 8 weeks was not considered excessive; in fact, it probably was not sufficient for return to full field duty. It was realized later that, in some cases, temporary reclassification to limited service for 3 months might have prevented the unqualified reclassification that later proved necessary.

There was only one serious complication in the series, a low-grade infection that progressed to ankylosis.

End results.—The end results secured in 63 of the 75 patients (76 arthrotomies) in this series showed that:

Twenty-nine men were doing full duty.

Twenty-seven men had been reclassified for limited service, aside from the three who had been so classified before operation.

Four had been discharged on CDD or had been retired from service because of the knee disability.

In their final evaluation of these patients before their discharge from the hospital, the operating orthopedic surgeons thought that all but 11 (including the three reclassified before operation) could do full duty. The event showed that they were wrong in 52 cases, 82.5 percent, though many of the men, as just noted, might have been salvaged for full duty if they could have been assigned to limited duty for 3 months after operation.

While the numbers are too small for statistical significance and the followup was only short term, an analysis of the figures in these 63 followed-up patients revealed certain facts of importance:

1. The best results after surgery were obtained in tears of the medial meniscus, cysts of the medial and lateral menisci, and osteochondritis.

2. A higher proportion of officers, noncommissioned officers, and air cadets returned to duty than the proportion of enlisted men. The discrepancy perhaps might be expected, the officer group having more incentive to return to duty and more opportunity to take an additional few weeks for rehabilitation.

3. Whether or not the injury was incurred in line of duty did not seem important, but it was interesting that:

a. Of 29 men known to be on full field duty after operation, injury had been incurred LOD in 14 and was EPTI in 15.

b. Of 27 patients reclassified after operation, 16 injuries were LOD and 11 were EPTI.

c. Of three patients on limited service at operation, two had LOD injuries and one lesion was EPTI.

d. Of four patients discharged because of knee disabilities, one had an LOD injury and the other three had EPTI lesions.

e. These figures mean that, of 63 patients followed up after operation, 33 had injuries incurred LOD and only 15 of these were sufficiently rehabilitated to return to their former military status, while 14 of the 30 patients with EPTI injuries returned to full duty.

4. Of the 27 patients reclassified for limited service, 14 had been in the Army less than 6 months, against nine of the 29 who returned to full duty. Apparently, seasoned soldiers and officers, with their basic training behind them, were more apt to return to full duty after arthrotomy for internal derangements of the knee. One also may speculate that commanding officers possibly made more allowance for veterans returning to duty than they did for new recruits.

5. A higher proportion of soldiers and officers in the Infantry were reclassified to limited service than in other branches of the Armed Forces. All patients with intra-articular fractures, with or without damage to the intra-articular cartilage, and all those with injury to both menisci were reclassified.

Disabilities of the Knee—Second Survey

In 1945, Lieutenant Colonel Willien, who had participated in the survey just reported, continued the investigation and secured minimum followup information on all of the 75 soldiers included in the first survey (*26*). At this time, 29 were on full duty, 18 were on limited service, 14 had been separated by CDD because of knee difficulties, seven had been separated on CDD for other reasons, and seven had been discharged under other regulations. The followup was by the method already described.

In other words, of 75 soldiers operated on at Fort Jackson in 1942, in spite of variable Army policies, more than six of every 10 men were salvaged for further Army duty: 29 for full duty, and 18 for limited duty. Nineteen of these men had been overseas. Four of the enlisted men had reached officer status, and another was then at officers' training camp. One had been wounded in action, and another had received the Bronze Star. Those on full duty, almost without exception, had no complaints referable to the knee except for some stiffness in damp weather.

Several of the men discharged for medical reasons were pursuing civilian occupations with no difficulty. Two men on limited service at the end of 2 years had no objective or roentgenologic signs of further trouble. Only one man, an officer, had been discharged for psychoneurotic reasons; evidently the selection of candidates for surgery had been effective from this standpoint.

The most striking feature of the 28 discharges is that 16 of them occurred during the August-October 1943 period, when WD Circular No. 161 was operative and the classification of limited duty was eliminated

(*6*) (p. 103). Under other regulations, many of these men, if not fit for full duty, probably could have been salvaged for some useful Army service. The figures in this series correspond with the study of disability discharges for the whole Army, published in December 1944 (*14*).

The figures in this second survey also showed that only 26 of every 100 men in the Infantry were likely to continue on full duty for 2 years after operations on the knee. One explanation might be the desire of all Infantry commanders to have in their organizations only physically perfect soldiers. Another possible explanation might be the desire of soldiers to escape the hazardous duties of infantrymen. It must be remembered, of course, that there had been some salvage; all of these men were unfit for Infantry duty before they were operated on.

The most important conclusion to be drawn from this second survey was that the complete rehabilitation of only 29 of 75 soldiers, 38.6 percent, did not warrant the performance of arthrotomy as a routine procedure. Men with a definite history of injury before induction should be reclassified or discharged, depending upon the seriousness of the knee damage; they should not be operated on. Men with LOD injuries should be discharged with the benefit of surgery if they desired it or kept on duty with surgery performed if it seemed indicated after careful evaluation, including evaluation of emotional stability.

This investigation also showed the importance of reconditioning facilities in all military hospitals, so that there could be gradual resumption of military duties while the patients were still under hospital control. The use of these facilities in this series undoubtedly resulted in a lower rate of reclassification or discharge after return to duty than might have prevailed otherwise.

Neither of these studies, it should be emphasized again, represents a scientific evaluation of the patients by the orthopedic surgeons who operated on them. Both do reflect each patient's own opinion, and the opinion of his commanding officer and unit medical officer, of the results of surgery on the knee joint, and they also reflect current War Department personnel policies.

Hallux Valgus

The outcome of another investigation by Colonel Cleveland and his associates at the Fort Jackson Station Hospital, on operations for hallux valgus, was even more discouraging than the followup study on knee surgery (*27*).

The study was conducted in the manner outlined for the knee operations, with the criterion of success or failure whether or not the patient could return to full duty or had to be reclassified for limited service, or discharged. A similar questionnaire was used (p. 106).

Basic data.—This study was carried out on 25 officers and men who

were operated on in 1942 for severe degrees of hallux valgus. In 14 cases, the operation was bilateral. Half of the patients were in the Infantry. The remainder were in the Field Artillery, Corps of Engineers, Army Air Corps, and Army Medical Department in that order. One was a Negro. One was a nurse.

The ages ranged from 21 to 38½ years, and averaged 28 years. Most of the patients were recent recruits; their period of service ranged from 7 days (four men had barely arrived on the post) to 8 years and 8 months. Only one man was in the LOD category; he had been in service for 21 months and had had trouble for the last 6 months.

Surgery and immediate disposition.—The 39 operations for hallux valgus were distributed as follows:

1. The Keller operation was performed 21 times on 12 patients, whose average postoperative hospital stay was 44 days. Three were on limited service before operation, and one was recommended for it after surgery. The eight other patients were returned to full duty. Healing was uncomplicated in all but one case. This patient had been treated for severe trichophytosis for a month before operation. Healing of the wound was by primary intention and he was discharged in good condition at the end of 42 days. A month later, he returned with an ulcer over the medial aspect of the affected toe. The ulcer had invaded the deep tissues and was followed by osteomyelitis of the phalanx and extrusion of a small sequestrum. Satisfactory healing finally occurred after a period of months and the patient was returned to limited service.
2. The McBride operation was performed 12 times on nine patients. Plaster was used routinely. Wound healing was very unsatisfactory in four cases, and the average period of hospitalization for these patients was 71 days. All, however, eventually were returned to full duty, their status before operation.
3. Simple excision of the exostosis was performed five times on three patients, whose hospitalization averaged 54 days. Wound healing was poor in one instance. Two of the men returned to full duty and one to limited service.
4. The Silver technique was used on one patient, with bilateral lesions, who was returned to full duty after 84 days.

As in all military surgery, hospitalization had to be extended in all of these cases far beyond what it would have been in civilian life because these men had to be returned to full duty, regardless of the status to which they were assigned.

End results.—It was possible to follow up 22 of these patients. Only seven, two of whom had had bilateral operations, were on full duty at the end of a year (one nurse, one officer, five enlisted men). In this group was the man who had been operated on 7 days after induction. Not included in it was the oldest of the 25 patients. He was returned to full duty for 6 months, then was honorably discharged for age, which meant that the surgical effort expended on him did not add to the fighting strength of the Army.

Fourteen of the 22 patients followed up were on limited service because of the condition for which the operation had been done. Three had been in that status before operation and two were recommended for it after surgery. The other nine had been returned to full duty, but could not

tolerate it and were subsequently recommended for reclassification by their unit surgeons.

None of the patients operated on required a CDD separation from service because of his feet. On the other hand, a procedure which restores to full duty (over a limited period of followup) only seven of 22 patients is of small benefit to the fighting forces, even though most of those who were returned to limited duty were benefited symptomatically themselves and also performed some useful service in the Army.

The figures are far too small to have any statistical value, but an analysis of them points to certain factors of importance in the results achieved:

1. The most important single factor in the results achieved apparently was the unilateral or bilateral nature of the operation. Of the seven patients who returned to, and remained on, full duty, five required only unilateral surgery. All five were in combat units and had difficult assignments. One of the other patients was a nurse, and, while nursing is arduous, it does not compare with the work required of a combat soldier.[4]

2. Five patients returned to full duty after McBride operations, against only two after Keller operations, but here, again, the laterality factor must be considered: Six of eight McBride operations were unilateral, against only three of 12 Keller operations.

Hallux valgus tends to be bilateral, but the deformity is generally greater, and is the source of more complaints, in one foot than in the other. In civilian practice, it is the custom to recommend bilateral surgery, to avoid a second operation. This small series shows the fallacy of that policy in military surgery. Bilateral operation left the soldier "literally without a leg to stand on," and probably explained why so few could return to full duty. As little surgery as possible should be done on soldiers, who are so dependent on their feet.

3. In spite of the poor results of the Keller operation in terms of patients (two) returned to duty, it is the operation of choice in hallux valgus. The technique is simple. Immobilization is not required. The cosmetic and functional results are satisfactory. Finally, hospitalization is materially shorter than in other procedures. With one exception, healing was satisfactory in all the cases in this series handled by this technique. A substantial number (four) of wounds healed badly after McBride operations, perhaps because of technical errors: In any operation performed with a tourniquet in place, the wound edges should be approximated loosely, with interrupted sutures.

4. Very few of the 14 patients in this series who returned to limited service after operation for hallux valgus would have failed to meet the minimum standards for induction as laid down in MR 1-9 (*5*), though

[4] All nurses operated on later at the Fort Jackson hospital and not included in this series also were restored to full duty.

FIGURE 5.—Lateral roentgenogram of foot, showing retained birdshot from gunshot wound 3 years before induction. Note traumatic arthritic changes. This soldier, although unfit for field duty, had a usable skill and was, therefore, retained in service.

they might have presented problems in reassignment. But surgery for preexistent hallux valgus for soldiers in training is likely to be successful in too few cases, in the sense of returning them to full duty, to justify its performance, especially if the lesions are bilateral. Among nurses, on the other hand, a high proportion of successes can be anticipated.

SPECIAL CONDITIONS

Among the chronic disabilities observed in training camps and in other organizations in World War II were old gunshot wounds (fig. 5); old fractures of various bones with residual disability; osteochondritis (figs. 6 and 7); Perthes' disease; Kienböck disease; old childhood deformities, such as bowleg (fig. 8), syphilitic saber tibia (fig. 9), and adolescent round neck; arthritis (fig. 10); anomalies of the spine (figs. 11–13); and disabilities of the feet and knees.

Some of these conditions were exacerbated by Army service. Some were readily remedied. But many of them were not, and many came under the restrictions against elective surgery already discussed. The majority of men in these latter categories had to be either assigned to limited service or separated from service by Certificate of Disability for Discharge.

Most of the wide variety of orthopedic anomalies observed in induction centers did not interfere with Army service. It would have been remarkable, considering the millions of men examined, if such conditions had not been observed. The spacing of the observations, however, was some-

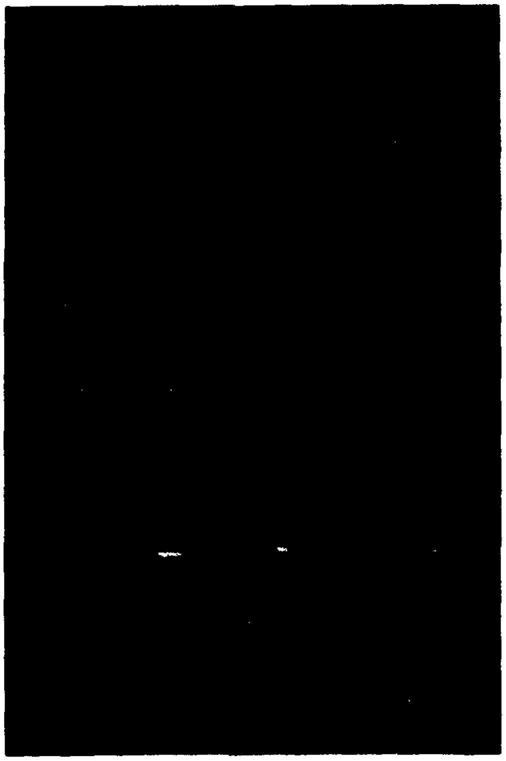

FIGURE 6.—Anteroposterior roentgenogram of forefoot showing old osteochondritis (Freiberg's disease) of head of second metatarsal. Note marked flattening, and congenital shortening of first metatarsal segment. Field duty was impossible for a soldier with such a painful disability, and treatment never was satisfactory.

times odd. At the Army Recruiting and Induction Station, New York, N.Y., 11 inductees were observed with triphalangeal thumbs, three of them within a few months of each other (*28, 29*). Then, more than 75,000 examinations were made before the other inductees with this anomaly were encountered. One of these anomalies was trifid and the others were bifid. A hereditary origin could be traced in five.

To avoid a great deal of repetition, most EPTI conditions are discussed in detail under appropriate regional headings. One or two conditions, however, warrant discussion here.

ARTHRITIS

Although the principal responsibility for arthritis, particularly of the nontraumatic type, rested with hospital medical departments, the ortho-

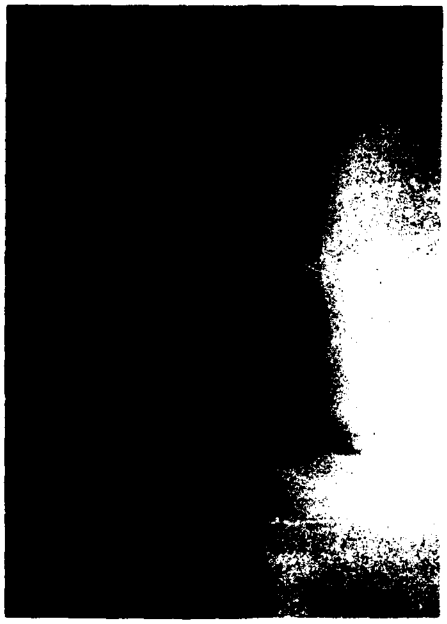

FIGURE 7.—Lateral roentgenogram of knee showing osteochondritis dissecans with multiple loose bodies. Note large defect of femoral condyle. When this condition was service-incurred (in this instance, it was not), the patients were operated on, but the period of postoperative disability was long, and only a few could be returned to duty.

pedic surgeon also carried a large share of the load. This was a surprisingly common diagnosis in patients brought before medical boards. At the station hospital at Camp Blanding, Fla., for instance, during the last 3 months of 1942, arthritis represented 5 percent of 1,000 CDD separations. About half of the arthritic group had had signs and symptoms before induction, and an emotional factor frequently was evident (p. 123). About 60 percent of the cases were of the infectious or rheumatoid type, about 30 percent of the hypertrophic type, and about 10 percent of the traumatic type. Eight patients, all young men, had experienced a sudden onset of monoarticular arthritis, followed by polyarticular involvement and progression of the disability.

About 95 percent of these arthritic patients were returned to duty, but the experience suggested to the examining officers that this cause of separation could be expected to increase in the future.

Army and Navy General Hospital

Development of facilities.—The Army and Navy General Hospital at Hot Springs, Ark., was designated as an arthritis center in a memorandum

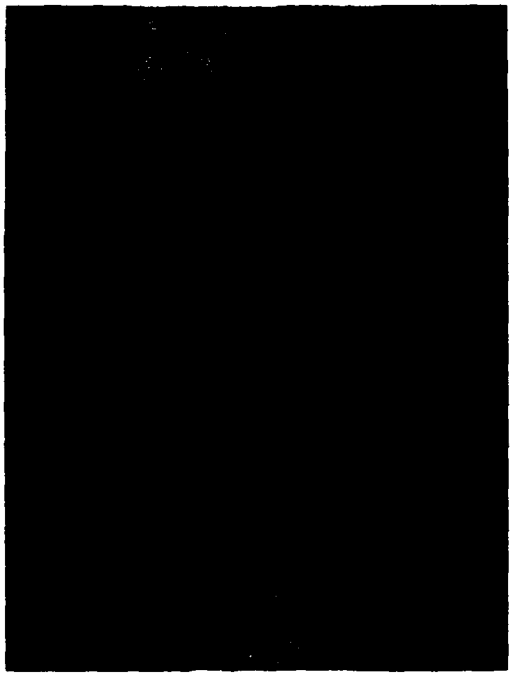

FIGURE 8.—Anteroposterior roentgenogram of left leg, showing tibia bowed in marked valgus, with tibiofibular synostosis, as result of overcorrection of bowlegs at 5 years of age. The operation was bilateral. On the right side, the overcorrection had been somewhat less and synostosis had not occurred. This soldier was unfit for full duty and had to be reassigned.

dated 17 December 1943 (*30*). This hospital was one of the so-called restricted institutions, which meant that all transfers to it had to be cleared through the Medical Regulating Officer, Surgeon General's Office. In May 1944, Headquarters Seventh Service Command informed its various installations of the request from The Surgeon General that facilities available at this hospital be utilized to maximum advantage, as they were not being utilized at this time (*31*). He particularly wished that patients with rheumatoid arthritis likely to benefit from the specialized treatment available at it be transferred to it as promptly as possible.

The Chief of the Medical Service acted as Director of the Rheumatism Center, Army and Navy General Hospital, and patients were treated cooperatively by the Medical Section, the Orthopedic Surgery Section, and the Physical Therapy Section (*32*). Two recognized specialists in rheumatic diseases were assigned to the center in 1943.

At the end of 1943, facilities for the Rheumatic Disease Section consisted of one

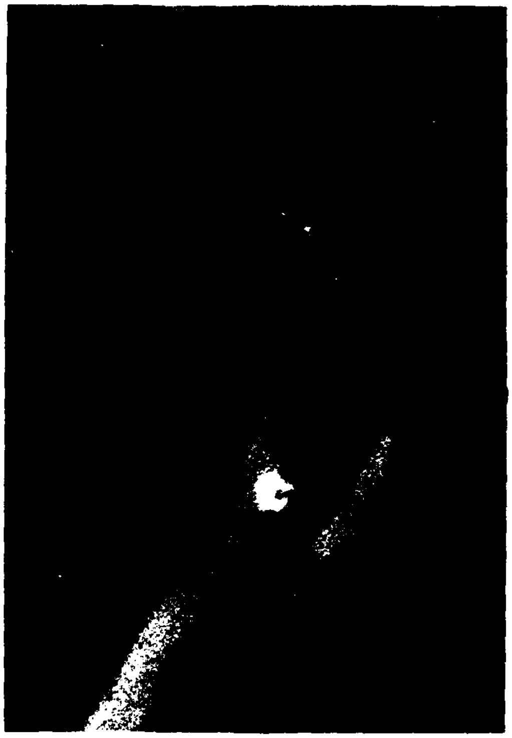

FIGURE 9.—Lateral roentgenogram of leg, showing typical saber tibia as result of childhood syphilis. Since this soldier was incapable of prolonged marching or standing, had a rather low mental age and no special skills, he was discharged from service.

ward with a 45-bed capacity and a portion of another ward. There had been 556 admissions, and 80 patients were currently under treatment. The section was responsible also for the supervision on other wards of patients who had arthritis, but in whom it was a secondary problem.

During 1944, the Rheumatic Disease Section was greatly enlarged and completely reorganized. It finally occupied eight wards, with bed capacities ranging from 60 to 83, and parts of five other wards, in addition to separate facilities for officers. Most of the patients were ambulatory and were cared for in the Eastman Annex to the hospital. Patients who were not ambulatory were housed in a separate ward in the hospital proper. During 1944, a total of 3,105 patients were treated, of whom 612 were officers. Admissions ranged from 56 in January to 613 in November and 568 in December. The daily census during this period ranged between 500 and 600. After 1 July, about 70 percent of the patients on the Medical Service were under the care of the section on rheumatic diseases. Only during the last 3 months of the year was the staff adequate for the patient load; then it consisted of three qualified specialists, one partly trained officer, and five officers in training.

During 1945, facilities of the Rheumatic Disease Section were the same as in 1944, but the workload was heavier; a total of 3,542 patients were cared for during the year.

FIGURE 10.—Lateral roentgenogram of ankle, showing longstanding traumatic arthritis of astragaloscaphoid joint. This case is a typical illustration of a large group of soldiers who were inducted with moderate to severe preexisting arthritis of the extremities, usually traumatic in origin. If these men had no skills usable in light-duty assignments, the best plan was to discharge them from service at once.

The daily census was between 500 and 700, not counting the 150 to 350 patients who were on furlough at all times. Officers assigned to the section included five qualified specialists, four partly trained officers, and nine officers in training. The officer-patient load ranged from 1 : 150 to 1 : 250, which was undesirably high.

Indoctrination.—Indoctrination was necessary both for medical officers assigned to the Rheumatic Disease Section and for the patients cared for on it. Weekly clinics on rheumatic diseases were conducted by the director of the section as part of the educational program for officers assigned to it, Medical Department Replacement Pool officers, visiting officers, and interested members of the staff.

In addition to the individual instruction given all patients by the ward officers, lectures and demonstrations to aid them in understanding their

FIGURE 11.—Anteroposterior roentgenogram of lower lumbar spine, showing wedge-shaped hemivertebra. This case is another example of the unwise induction of a man with a severe congenital defect, whose disability made it impossible for him to perform any useful function in the Army.

disease were conducted by these officers with the assistance of the Physiotherapy Section and the dietitian. The subjects discussed included the meaning of rheumatism and arthritis; osteoarthritis and its management; home physical therapy (motion pictures), fibrositis; and fads, fancies, and false concepts in arthritis. This program, which was instituted in 1944, was so successful that it was expanded the following year to include mechanics of the body and joint disability, rheumatoid spondylitis and its management, and shoulder disabilities and their management.

Research studies.—Although investigative work at the Army and Navy Hospital was sharply limited by the heavy workload, some clinical studies were carried out in 1944 and 1945, covering the military aspects of certain types of rheumatic disease; psychogenic rheumatism and its differentiation from fibrositis; the differential diagnosis of postgonorrheal rheumatoid arthritis and gonorrheal arthritis; palindromic (recurrent) rheumatism; cardiac changes in rheumatoid arthritis; the diamidines in the treatment of rheumatoid arthritis; clinical and pathologic features of psoriatic arthritis and psoriatic arthropathy; various aspects of rheumatoid spondylitis, including a study of associated cerebrospinal fluid changes; roentgen ray therapy in the treatment of rheumatoid spondylitis; and studies of special

FIGURE 12.—Anteroposterior roentgenogram of lower lumbar spine, showing sacralization of fifth lumbar vertebra. The transverse processes of the anomalous vertebra are articulating with the upper portion of the sacrum. These so-called transitional vertebrae, observed with surprising frequency, were disabling if an anomalous joint was present, either unilaterally or bilaterally. Discharge from service usually was necessary.

drugs, under the direction of Lt. Col. (later Col.) Philip S. Hench, MC, of the Mayo Clinic.

Ashburn General Hospital

The Rheumatism Center at Ashburn General Hospital was authorized as a rheumatism center on 25 August 1944 and became operational on 1 September 1944 (*33*). The original allotment of 729 beds was increased by using barracks for wards, and, by 1 January 1945, the bed capacity was 1,661.

During 1945, a total of 3,534 patients were admitted to this center, 400 per month during the first 8 months. By the end of the year, only 17 beds were occupied. This center was operated on the same general principles as the center at the Army and Navy General Hospital.

Clinical Considerations

As table 1 shows, the patients admitted to the Rheumatism Center at the Army and Navy General Hospital represented all of the common forms of arthritis. Among the uncommon conditions not listed were arthropathies

FIGURE 13.—Lateral roentgenogram of lumbar spine, showing spondylolisthesis with forward displacement of fifth lumbar vertebra on sacrum. Most men inducted with this congenital defect could not do satisfactory duty of any kind in the Army and had to be discharged from service.

associated with chronic ulcerative colitis and with bacillary dysentery; Reiter's syndrome; keratoderma blennorrhagica (with and without associated gonorrhea); fragilitas ossium; acromegalia; osteitis deformans (Paget's disease); Sudeck's bone atrophy; posttraumatic periarticular fibrosis (Leriche's disease); protrusio acetabuli (Otto pelvis), pulmonary osteoarthropathy; and Costen's syndrome.

Rheumatoid spondylitis was encountered with unusual frequency at the Army and Navy General Hospital, and there was also a high incidence of atypical forms of rheumatoid arthritis, often of acute or subacute onset. Rheumatoid arthritis precipitated by gonorrhea, or occurring coincidentally with it, was encountered much more frequently than the classical form of gonorrheal arthritis.

Infectious arthritis after operation was very infrequent in World War II, as the result of good surgery and efficient antibiotic therapy. In 150 arthrotomies of the knee reported by Maj. William F. Stanek, MC, from Camp Crowder, Mo., it occurred only once (*34*).

Osteoarthritis (hypertrophic or degenerative arthritis) was a considerable problem during the war. Many men were inducted with a clear-cut history of repeated episodes, and the condition was preexistent in most cases, though a considerable number of patients developed it after trauma. At the station hospital at Camp Livingston, Maj. (later Lt. Col.) Gene D. Caldwell, MC, noted degenerative changes in the medial aspect of the

TABLE 1.—*Distribution of types of arthritis in first 2,000 patients admitted to the Rheumatic Disease Section, Army and Navy General Hospital, Hot Springs, Ark.*[1]

Type of arthritis	Cases	
	Number	Percent
Rheumatoid arthritis:		34.3
Peripheral	390	
Spondylitic	209	
Peripheral and spondylitic	87	
Psychogenic rheumatism:		18.8
Pure (without organic disease)	231	
Superimposed (with organic disease)	101	
Residual (following organic disease)	43	
Fibrositis, primary (periarticular, intramuscular, bursitis, tendinitis)	272	13.6
Osteoarthritis:		12.4
Primary	210	
Secondary	39	
Rheumatic fever (with and without carditis)	41	2.0
Gonorrheal arthritis	27	1.4
Gouty arthritis	18	.9
Specific infectious arthritis (tuberculous, meningococcic, staphylococcic)	9	.5
Rarer types of arthropathies (nonspecific monarthritis, palindromic, psoriatic; with disseminated lupus, and so forth)	43	2.1
Joint tumors (osteochondromatosis, synovioma)	8	.4
Miscellaneous conditions (sciatica, internal derangements, spinal anomalies, ruptured intervertebral discs, traumatic synovitis, and so forth)	176	8.8
Unclassified rheumatism and arthritis	96	4.8

[1] Data from annual report, 29 Jan. 1945.

meniscus in 69 of 83 meniscectomies (*35*). The changes in the meniscus were in direct proportion to the duration of the internal derangement and were not related to the character of the original trauma. They apparently occurred more rapidly and were more extensive if the original trauma caused relaxation or rupture of the ligaments along with the injury to the meniscus. Major Caldwell's practice during arthrotomy, if he saw an area of degeneration in the femoral articular surface opposite the meniscus, was to remove the meniscus in toto, even though it appeared normal, and invariably he found a lesion of the posterior third.

Experience showed that, when preexistent arthritis was of any severity, whether or not it was of traumatic origin, the ability of men to withstand training and do combat duty was highly questionable. Five patients hospitalized at the same time at the station hospital at Camp Crowder were cited by Major Stanek as a warning against the induction of registrants with arthritis (*34*). These men underwent combat training to the limit of their ability, but they proved unable to perform any military duty. All entered the hospital completely disabled and with their preexistent

disease unquestionably exacerbated by service. All were operated on, in accordance with the regulation that maximum medical benefits must be achieved before men were separated from service; one was retained on limited duty, but the other four could not be salvaged.

The presence of arthritis did not contraindicate the excision of a damaged meniscus, but serious reflection was necessary before surgery was undertaken. It seldom was warranted unless the man was of real military value and was truly desirous of being a soldier.

Every patient with arthritis of any variety had to be handled individually and treated according to his special needs. From the standpoint of active treatment, there was not a great deal to be done. Many internists, in fact, stated bluntly that hypertrophic arthritis was not amenable to satisfactory therapy in a military environment. No new drugs for arthritis were developed during the war. Physical therapy was probably the most effective of all modalities in that it offered at least temporary relief, but a soldier who required prolonged application of this kind of therapy was very unlikely to be an efficient soldier, however strong his motivation.

In many instances, of course, motivation was not strong. Psychogenic arthritis was a frequent condition. At the center at the Army and Navy General Hospital, it accounted for 18.8 percent of all admissions in 1944 and for 14.6 percent, in 1945. Depression, preoccupation, lack of interest, and other emotional overlays frequently became evident as the history was elicited. At some hospitals, such as the station hospital at Camp Blanding, it was the custom, if no objective cause for the complaints could be found in the musculoskeletal system, to have the neuropsychiatric section work up the patient. If an organic cause could be eliminated, the practice at the Army and Navy General Hospital was to transfer him to the neuropsychiatric section, for individual and group therapy.

The outlook in these cases and in many other cases of arthritis was not hopeful. Once the average soldier was aware that actual (roentgenologic) evidence existed for his disability, he was very likely to respond poorly to any sort of treatment and to use his efforts to have his duty assignment changed to something less strenuous, or to have himself separated from service. Patients with psychogenic arthritis presented much the same problem. As the war progressed, more and more medical officers came to believe that separation from service was really the wisest solution in all such instances.

MUSCLE FIBRODYSTROPHY

General considerations.—Muscle fibrodystrophy (also termed "chronic myofibrosis," "chronic muscle contractures," "muscular fibrosis," and "tightness of the ligamentous structures") is an illustration of a preexistent disease, not very well known and not very frequent, that still prevented a relatively large number of men from doing full military duty (*36*). It may be defined as chronic, nonprogressive dystrophy affecting the skeletal

muscles, notably the erector spinae, hamstrings, calf muscles, and extensors of the toes, and taking the form of generalized weakness and contractures.

Maj. Robert Bingham, MC, who developed a special interest in the condition, personally observed 264 cases in about 12,000 patients in orthopedic clinics and wards of Army hospitals over a 3½-year period in Mississippi, Colorado, and California, and in two other hospitals in the Pacific Ocean Areas. Another medical officer estimated that he had seen about 200 cases in approximately 20,000 patients admitted to an evacuation hospital in the South Pacific over a 2-year period. No single part of the United States contributed a disproportionately larger number of cases than any other.

The gross and microscopic pathologic changes in this condition were not clarified during the war, since few muscle biopsies were justified or performed. The few specimens examined suggested an abnormal replacement of skeletal muscle fibers by connective tissue. No opportunity existed for physiologic or neuropathologic investigations, and the analysis of Major Bingham's series was limited to clinical observations (*36*).

Etiology.—The chief symptoms in these cases were poor coordination, rapid exhaustion on physical exertion, and inability to acquire skills that depend upon fine muscle movements. The onset, when it was known, dated back many years, sometimes 10 years or more. Progression invariably was denied, and nothing in the history or examination suggested an active disease process or anything but a residual physical disability. The majority of the patients were not aware of any serious physical handicap until they were subjected to the stresses of military training or subsequent combat duty. They then found themselves without physical stamina and strength for their tasks.

Of the 264 patients studied, 112 dated their disability to some definite illness in childhood. In 48 instances, this illness was known to be infantile paralysis; in 64 other cases, there were episodes suggestive of this condition though it had not been so diagnosed. There was no difference in the symptoms presented by those with positive or suspected histories of poliomyelitis and those without such histories, and it was concluded that this disease was probably the etiologic factor in all cases. The assumption is supported by the generally acknowledged high incidence of nonparalytic and unrecognized forms of poliomyelitis.

Clinical picture.—Inquiry revealed a history of the symptoms just listed. Most of the men had followed sedentary occupations and had unusually high records of intelligence and social and business achievement, but they never excelled in sports.

Physical examination revealed three types of body conformation and development:

1. An asthenic habitus and poor muscular development (168).
2. A heavier build, sometimes verging on obesity, with abnormal depositions of fat (80).

3. Good muscle devlopment in individuals who were "musclebound" (16).

Of the 264 patients studied, 84 had no deformities and 180 had a total of 244 mild deformities, including scoliosis (22); round sholders (46); exaggerated lordosis (60); inequality in the length of the legs (11); unilateral muscle atrophy (21); genu recurvatum (3); pes planus (18); pes cavus (33); cockup toes (26); and miscellaneous deformities (4). The frequency of postural and static deformities is notable in this list. Slight to moderate atrophy of the thigh and calf muscles was frequent, but there were no instances of weakness or atrophy of the muscles of the abdomen, trunk, or upper extremity. One finding common to all patients was contracture and shortening of the sacrospinalis and hamstring muscles; a contracture in one of these muscles almost invariably was associated with a contracture in the other.

Sensory examinations and examinations of the cranial nerves were always normal, but reflex responses and degrees of muscle atrophy varied widely.

In the 42 patients hospitalized, all laboratory examinations, including roentgenograms of the chest, were normal. In 20 patients studied roentgenologically, all bones and joints were normal except for one congenital anomaly of the lumbosacral joint.

Diagnosis.—The patients in this series frequently were referred to the orthopedic section from the neuropsychiatric wards and clinics with such diagnoses as neurasthenia, effort syndrome, psychopathology, and suspected malingering, as well as sprains, strains, acute polyarticular rheumatism, and tenosynovitis. There frequently was justification for the development of a mild psychoneurosis because of the symptoms, for which there seemed no explanation, but the patients resented being considered psychoneurotic; and their strenuous efforts to meet the duty requirements, at the expense of pain, discomfort, and fatigue, were sufficient, in themselves, to negate such a diagnosis. The absence of progression in the physical disability seemed to be the most characteristic and pathognomonic feature of the syndrome.

The differential diagnosis concerned anterior poliomyelitis; myositis or chronic infectious myopathy; rheumatism or rheumatoid arthritis; chronic intramuscular fibrositis in the residual stages; and myopathies and hereditary and familial diseases of the neuromuscular structures. All were readily excluded.

Therapy and end results.—Treatment was symptomatic, consisting of physical therapy (usually infrared radiation and massage), aspirin, and light duty for several days. In the 42 cases in which hospitalization was necessary, treatment consisted of bed rest, more intensive physical therapy, and active exercises designed for special muscle groups. Psychotherapy was occasionally used. Light sports were recommended, to the limit of the man's ability.

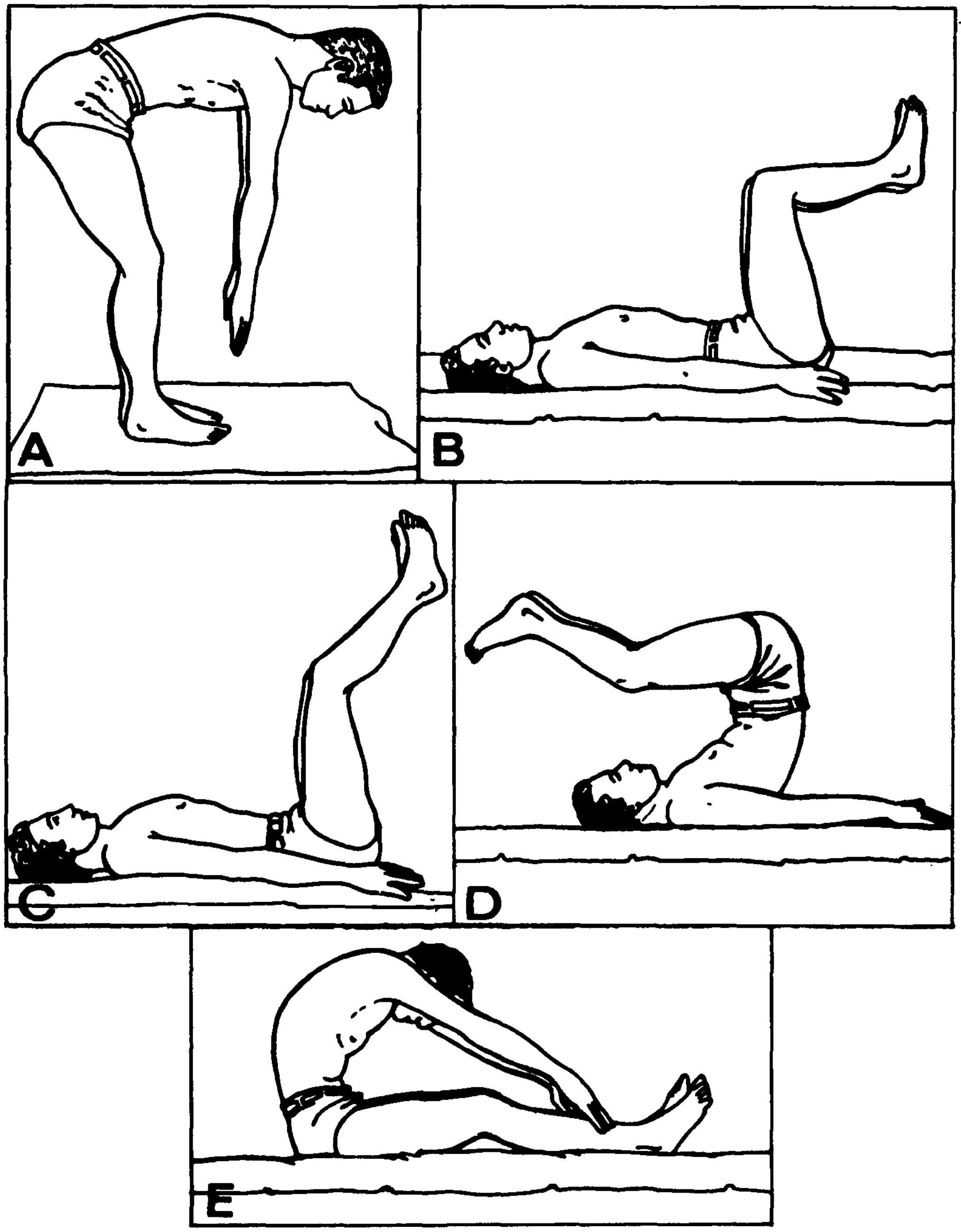

FIGURE 14.—Demonstration of contractures in muscle fibrodystrophy. A. Contractures of erector spinae and hamstrings evident in forward bending test. B. Contractures of calf muscles evident in ankle dorsiflexion test. C. Contractures of hamstrings evident in attempt to extend knees fully. D. Contractures of thoracic muscles evident in attempt to touch toes to floor above head. E. Contractures of erector spinae evident in trunk flexion test. (Bingham, R.: J. Bone & Joint Surg. 29: 85–96, January 1947.)

Results of treatment were generally good. Of the 264 men in the series, 72 were reassigned to limited (less physically taxing) duties, but none were separated from service. The reaction to physical therapy furnished an excellent differential diagnostic point: Psychoneurotic patients were relieved seldom, or relieved only transiently, by it, and their symptoms might be expected to recur when they were ordered to duty. This was not true of patients with muscular fibrodystrophy.

The following is a typical case history of this condition:

Case 1.—A 22-year-old white soldier, in the fourth week of basic training, reported at sick call with his chief complaint severe pain for the past 3 days in the muscles of his back and legs, after a 10-mile hike with full infantry pack. He was now unable to participate in hikes or in morning calisthenics.

He had had "muscular rheumatism" at 16 years of age, characterized by generalized muscle soreness, and he never again felt as strong as he had felt before this illness. Although he was tall and heavy (6 feet, 175 pounds), he was clumsy, easily exhausted, and in general, he tired earlier than did others engaged in the same types of activity. He attempted to learn typing, but gave it up after 3 months.

In spite of this history, the patient was inducted with a top classification for physical fitness and suitability for combat duty. Calisthenics proved more difficult for him than for his mates. He was unable to touch the floor, he had difficulty in keeping his abdomen flat, and his feet and legs were readily fatigued after he had run short distances. He had no trouble on short hikes, but long hikes and marches on paved roads and parade grounds produced soreness in the legs and thighs which did not disappear after a night's rest.

Physical examination showed a moderately increased lumbar lordosis and a prominent and relaxed abdomen. The little toes on both sides were cocked up and barely touched the floor when the patient was standing. The skeletal muscles apparently were normal in size and contour, but the tissues were softer than normal and muscle tone was very poor. When the joints were tested, it was evident that the apparent limitation of range of motion was not caused by any abnormality of articulation of the spine and the extremities but by the limited stretch of the muscles. The neurological examination was essentially normal. Roentgenograms of the lumbar spine and feet were negative. The contractures (fig. 14) involved the sacrospinalis, hamstrings, gastrocnemius, soleus, and thoracic muscles.

The diagnosis was moderate muscle fibrodystrophy apparently caused by an undiagnosed illness at 16 years of age.

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CHAPTER IV

March Fractures

James J. Callahan, M.D.

GENERAL CONSIDERATIONS

A relatively infrequent, but nonetheless relatively important, injury to which soldiers are liable, practically always during their training periods, is the condition most generally known as march fracture. During World War II, a number of writers used the term "insufficiency fracture," and the injury has been called by a variety of other names, including stress fracture, fatigue fracture, pied de marché, pied forcé, and recruits' disease (*1–3*). As several observers have pointed out, march fracture is really not an entirely accurate term, in view of the reports of the occurrence of the injury in civilians, and, in some cases, the complete absence of the marching factor. This term, however, has the sanctity of usage, and it seems, to date, to be the preferred term in the U.S. medical literature.

The most generally satisfactory definition of march fracture was formulated by Hartley (*2*), a British observer, in 1943. He described it as partial or complete fracture which can be shown roentgenologically to have occurred in apparently normal bone or in which roentgenologic demonstration of callus formation, or the subject's subsequent clinical and roentgenologic course, warrants the assumption that microscopic or molecular fracture has occurred. The absence of direct violence is a requirement of diagnosis. Jansen's (*4*) earlier definition, that march fracture is an edematous swelling in the metatarsal region of the foot that occurs in persons, whether military or civilian, who have been forced to walk beyond their strength, is obviously less satisfactory and less inclusive, particularly because it makes no mention of roentgenologic evidence of injury.

HISTORICAL NOTE

Early Observations

A considerable literature on the subject has grown up since march fracture was first recognized more than a century ago. Curiously, there are definite cycles of interest in this injury, which are not always related to war (some of the basic information on these fractures was derived from civilian observations), while in the interims, there will be no reference to it

in the literature. The bulk of the literature, particularly the early literature, is European. This is not surprising, since the continental nations of Europe have always maintained large standing armies, while, until recently, the United States did not. With a single notable exception, a report from Burma by Capt. James G. Donald, MC, and Capt. William T. Fitts, Jr., MC (*5*), based on a forced march made under combat conditions, all material on this subject from the U.S. Army in World War II is from training areas in the Zone of Interior.

Unless otherwise indicated, the following historical information is derived from the comprehensive reviews of the literature of march fracture made by Dodd (*6*) in 1933, Meyerding and Pollock (*3*) in 1938, and Maj. Harold M. Childress, MC (*7*), in 1943. In evaluating the earliest reports of this condition, the reader should bear in mind that Roentgen's discovery of X-rays was not made until 1895.

There is general agreement that march fracture was reported for the first time in 1855, by a German military surgeon, Breithaupt, who described several instances of persistently edematous and painful feet after forced marches. He attributed the condition to traumatic inflammation of the tendon sheaths on the dorsum of the forepart of the foot. In 1877, another German military surgeon, Weisbach, described the same condition under the term "syndesmitis metatarsea." He thus located the lesion in the ligaments rather than in the tendons.

Between 1887 and 1897, a number of observers described the injury in French soldiers, attributing it, variously, to tendinitis, osteoplastic periostitis, rheumatic osteoperiostitis, and periostitis complicating mediotarsal arthritis. In 1897, Busquet recognized three steps in the pathologic process: (1) direct primary periostitis caused by repeated slight shocks in the forepart of the dorsum of the foot, for which the transverse furrow in the heavy military boot was chiefly responsible; (2) indirect traumatic periostitis; and (3) diathetic periostitis, with periostitis the predisposing, and trauma the localizing, factor.

Up to this time (1897), the true nature of the lesion under discussion was not recognized because all observations were necessarily clinical. In this year, Stechow, of the Prussian Guard, reported 36 march fractures studied by roentgenologic methods. At the same time, he described what is still a typical instance:

Case 1.—After a long march, a soldier experienced a burning sensation in the mid portion of the right foot. The following morning, although the affected foot was swollen, he marched for an hour, during which the swelling and pain became worse. When he was examined, there was no discomfort on pressure over the first and fifth metatarsals, but the pain of which he complained was increased by pressure over the proximal half of the second metatarsal bone. Twenty days later, a firm mass appeared in the region of maximum tenderness, and roentgenologic examination showed a fracture of the proximal half of the second metatarsal, with callus formation.

World War I

There is a curious lapse in the literature of march fractures during World War I. An investigation of the medical indexes under all appropriate headings has brought to light only a single article, by Capt. A. Howard Pirie, CAMC (*8*), who reported two cases, both of which he observed the

same day, and who mentioned six others identified in the course of 13,000 roentgenologic examinations. Neither the British nor the U.S. official medical histories of the war list the injury, and a search of the records in the Surgeon General's Office produced equally barren results. There is also no mention of march fractures in the manual on orthopedic subjects prepared early in World War II by the Subcommittee on Orthopedic Surgery, Division of Medical Sciences, National Research Council (*9*).

The assumption seems warranted that march fracture was not a condition of great consequence in the U.S. Army in World War I for several possible reasons:

1. These injuries actually were infrequent. There is indirect support for this inference in an account by Lt. Col. Edward L. Munson, MC (*10*), published in 1917, of the effect of marching on "newly raised troops." This particular march covered 165 miles and was carried out by militia who never before had such an assignment. It is true that many of the 389 soldiers sent back from the marching column to the base hospital had trouble with their feet, but the author specifically states that "foot soreness" was not of significance in the nonefficiency rates. One regiment of 1,300 men carried out the entire march without the loss of a single man for this reason. This excellent record was attributed to the careful attention given to the care of the feet, a theory that the World War II experience serves to corroborate.

2. An obvious reason for the apparent absence of march fractures in World War I was that training in this war was relatively brief and untaxing as compared with the hard training required in World War II (p. 148). Training in World War I lasted only 6 to 8 weeks, as compared with the 17 weeks of basic training required in World War II, and marches were usually conducted over soft, level ground instead of over the difficult terrain purposely chosen for training in World War II.

3. Soldiers who complained of pain and other foot disabilities in World War I were likely to be taken out of the line of march as soon as they reported their difficulties and were thus protected, as it were, against march fractures. Foot disabilities of various kinds were frequent, as is shown by the extensive discussion of the subject in the official history of the Medical Department in the First World War (*11*). The shoes supplied apparently were excellent, but there were numerous complaints about the socks, which seem to have been responsible for many instances of sore feet.

4. Perhaps the most valid explanation for the absence of any official report of march fractures in World War I is that the injury, if it did occur, was obscured by the simple and all-inclusive diagnosis of "sore feet." This supposition is borne out by informal questioning of a number of World War II medical officers who were in service as medical students or young medical officers in World War I. Col. I. Mims Gage, MC, Surgical Consultant for the Fourth Service Command in World War II, had no doubt that some of the "sore feet" he had observed in World War I really were march fractures, though he recollected the number as small.

5. Finally, it must be remembered that, while roentgenograms were employed widely during World War I, their use was by no means routine, as it was in World War II, nor was the roentgenologic technique so precise then as it was in the Second World War. It seems highly probable, therefore, that some march fractures which did occur were overlooked, partly because roentgenologic examination was not carried out and partly because, when it was employed, the films were not of sufficiently good quality to demonstrate them. In its early or acute stage, this is not an easy fracture to demonstrate roentgenologically, even on good films.

INCIDENCE AND MILITARY SIGNIFICANCE IN WORLD WAR II

In any analysis of the incidence and military significance of march fractures in World War II, certain background facts must be borne in mind:

1. These injuries practically always occurred in ground troops, who formed the bulk of combat troops and who were in short supply throughout the war.

2. Even with the motor transport supplied so generously in World War II, the physical demands on an infantryman were enormous, and any disability that affected his feet instantly reduced his total military, let alone his combat, effectiveness. The situation in this respect was analogous to the losses from trenchfoot (*12*), though cold injury, of course, affected much larger numbers of combat troops.

3. Even when the soldier was on limited service (a category that vanished as the war progressed) or when he was assigned to light duty, the physical demands on him frequently were heavy, and he often was required to walk or stand to the point of actual strain.

March fractures were not coded as such until 1943, and the number was, therefore, greater than official statistics show. The great majority occurred in the Zone of Interior, in the course of training. Many were multiple.

The incidence of march fractures is insignificant in relation to the 4,194,000 enlisted men and 230,000 officers who served in the Army Ground Forces during World War II (*13*). In the aggregate, however, these injuries represented a large loss of manpower (p. 154), and for that reason, they assumed a real military significance. Furthermore, they had a medicolegal significance: Any soldier who suffered permanent impairment of function would be eligible, at least theoretically, for a disability pension.

The largest number of march (insufficiency) fractures collected in World War II—1,157—originated at Camp Wheeler, Ga., and were reported in three series by Lt. Col. Clarence W. Hullinger, MC (*1, 14, 15*), with the collaboration in the first series of Maj. (later Lt. Col.) William L. Tyler, Jr., MC (*1*). In 207 instances, bones other than the metatarsals were affected (p. 157).

The second largest number of collected cases was reported by Lt. Col. Abraham Bernstein, MC, and his associates (*16*) from Camp Wolters, Tex. It consisted of 724 fractures, all in the metatarsals, in 692 infantrymen.

As would be expected, the majority of march fractures observed in World War II occurred in young men because young men predominated in the Army. In the first series of 313 fractures in 300 soldiers reported from Camp Wheeler (*1*), the ages of the men in the group roughly paralleled the ages of all the trainees in the camp at the time.

Lt. Col. James J. Callahan, MC, Consultant in Orthopedic Surgery, Fourth Service Command, in investigating the period of training at which fractures occurred, was able to relate this factor to age. Relatively older men (that is, men in the 28- to 30-year group) tended to sustain their fractures within the first 4 to 6 weeks of training. Younger men, who marched all day and then danced and otherwise exerted themselves as late as was permitted at night, without giving themselves adequate opportunities for rest, tended to sustain them earlier. In the 692 men studied by the Camp Wolters group (*16*), the time of occurrence of the fractures ranged from the third to the 17th week of training, with the highest incidence between the sixth and 10th weeks. In this series, there were 15 fractures in the fifth week, 96 in the sixth, 102 in the seventh, 96 in the eighth, 85 in the ninth, and 79 in the 10th. There were only 34 injuries in the 11th week, and, thereafter, the incidence was steadily downward.

For some reason, march fractures were not frequent in Negro troops. In the first series reported from Camp Wheeler (*1*), only eight of the 300 men with fractures were Negroes. Maj. William E. Allen, Jr., MC (*17*), in reporting a case in a company cook, commented that the incidence of this injury at this all-Negro Army post (Fort Huachuca, Ariz.), where thousands of troops had been in training over extremely rocky terrain for the past 3 years, was very low when compared with the incidence at other posts.

As a general rule, march fractures were observed only in station and regional hospitals. They seldom were seen in general hospitals unless the soldiers who had sustained them had other conditions that required treatment in this type of hospital.

SITES OF METATARSAL MARCH FRACTURES

While march fractures may occur in various locations in the foot and elsewhere in the lower extremity, the majority observed in U.S. Army troops in World War II occurred in the metatarsal bones (figs. 15–21) and the majority of the metatarsal fractures occurred on the right side.[1] This statement holds for all reported series in which the numbers were large enough to be significant. The most obvious explanation is that the soldier was likely to carry his load, or to carry a heavier load, on the right side.

In the 1,157 march fractures reported from Camp Wheeler (*15*), in 890 of which the metatarsals were involved, and in the 724 fractures of metatarsals reported from Camp Wolters (*16*), the anatomic distribution was as follows:

[1] For convenience of discussion, fractures in locations other than the metatarsals are described under a separate heading (p. 157).

FIGURE 15.—Anteroposterior roentgenogram showing march fractures of second, third, and fourth metatarsal bones of left foot 6 months after injury, which probably occurred on the soldier's second 15-mile hike. He had no treatment and continued on duty after a single visit to the infirmary. Note the markedly atavistic forefoot. This man wore a size 15-½ EE shoe, and discharge from service was recommended. (Leavitt, D. G., and Woodward, H. W., J. Bone & Joint Surg. 26: 733–742, October 1944.)

Site of fracture	*Number reported by Hullinger (15)*	*Number reported by Bernstein et al. (16)*
Right foot	617	426
Left foot	540	298
First metatarsal	81	2
Second metatarsal	322	319
Third metatarsal	445	374
Fourth metatarsal	39	25
Fifth metatarsal	3	4

The two series just tabulated differ from each other in only one respect, the striking disparity in the incidence of fractures of the first metatarsal bone, two in 724 fractures against 81 in 890 fractures. No explanation can be advanced for this considerable difference.

FIGURE 16.—March fractures of second and fifth metatarsal bones of left foot investigated 13 days after onset of symptoms. (Top) Anteroposterior roentgenogram. (Bottom) Oblique roentgenogram. (Bernstein, A., Childers, M. A., Archer, M. C., Fox, K. W., and Stone, J. R.: Am. J. Surg. 71: 355–362, March 1946.)

In the combined series of 1,157 march fractures reported from Camp Wheeler, 81 (10 of which were multiple) were bilateral, and 61 others were multiple (from two to four bones each) but unilateral. In the first series reported from this camp (313 fractures in 300 men), analysis of 306 cases showed the proximal third of the metatarsal fractured in 17 instances, the middle third in 131, and the distal third in 158. In the 166 fractures (in 155 subjects) reported from Camp Barkeley, Tex., by Lt. Col. (later Col.) Furman H. Tyner, MC, and Lt. (later Capt.) Walter T. Hileman, MC (*18*), the respective figures in 163 cases were 3, 70, and 90.

FIGURE 17.—March fractures of second and third metatarsal bones of right foot. The proximal fracture in the second metatarsal, which went untreated, is the more recent. (Left) Anteroposterior roentgenogram of right foot, 26 March 1943. (Right) Same, 4 months later. Note massive hypertrophy of second metatarsal bone. (Leavitt, D. G., and Woodward, H. W.: J. Bone & Joint Surg. 26: 733–742, October 1944.)

PATHOLOGIC PROCESS AND MECHANISM OF INJURY

As might be expected in a condition of this kind, not a great deal is known about the pathologic process because there is no legitimate reason, in most cases, for investigating it. The first histopathologic studies, reported by Straus (*19*) in 1932 and Dodd (*6*) in 1933, were in civilian patients and were the result of incorrect diagnoses. There was no history of trauma in either instance, and the biopsies were carried out to confirm the suspected diagnosis of sarcoma. In each instance, a fracture of the second metatarsal bone was found.

No known pathologic examination was made in a march fracture in U.S. Army troops in World War II, but studies made by Maj. Samuel H. Nickerson, MC (*20*), from Camp Maxey, Tex., might be cited in this connection:

Impressed by the similarity between the cortical break as it appeared in the femur and in the metatarsal, he secured thin, waferlike longitudinal sections through the shafts of these round bones and examined them under transillumination. It immediately became evident that many longitudinal striations extended in the long axis of the cortex, producing, in effect, a lamellation or lamination of the dense cortex. These observations suggested to him that the haversian system has the effect of a static

FIGURE 18.—Anteroposterior roentgenogram showing healing march fractures of second and third metatarsal bones of apparently the same duration. They had not been treated and were still painful at the end of 4 months. (Leavitt, D. G., and Woodward, H. W.: J. Bone & Joint Surg. 26: 733–742, October 1944.)

skeletal framework, which enjoys a tensile strength roughly analogous to that of a set of juxtaposed leaves of an automobile spring. Major Nickerson then reasoned that, if a force that causes an outward bowing of this laminated system continues to the point of fracture, the outermost layers, which are closest to the periphery, will burst or "be sprung" first. The more centripetally placed layers will be bent but not broken.

He believed that a march fracture passes through three phases, as follows:

1. Nutritive changes caused by hyperemia and manifested by a zone of rarefaction, with local weakening of architecture, followed by periosteal proliferation on the contralateral side. This is the latent or asymptomatic stage.

2. A beginning break in the cortex. If early periosteal proliferation occurs, the fracture will be minimal, with no displacement. If the periosteal reaction is slight or absent, the fracture will be complete and displacement is possible. This is the symptomatic stage.

3. Formation of mature callus, chiefly on the contralateral side. This the healing stage (fig. 21).

Major Nickerson's original report concerned 11 march fractures in various locations. While the report was in press, he encountered more than 100 additional march fractures and found the observations he had made in the smaller series generally corroborated in the larger number. In summary, if an early periosteal reaction occurred, the fracture frequently was

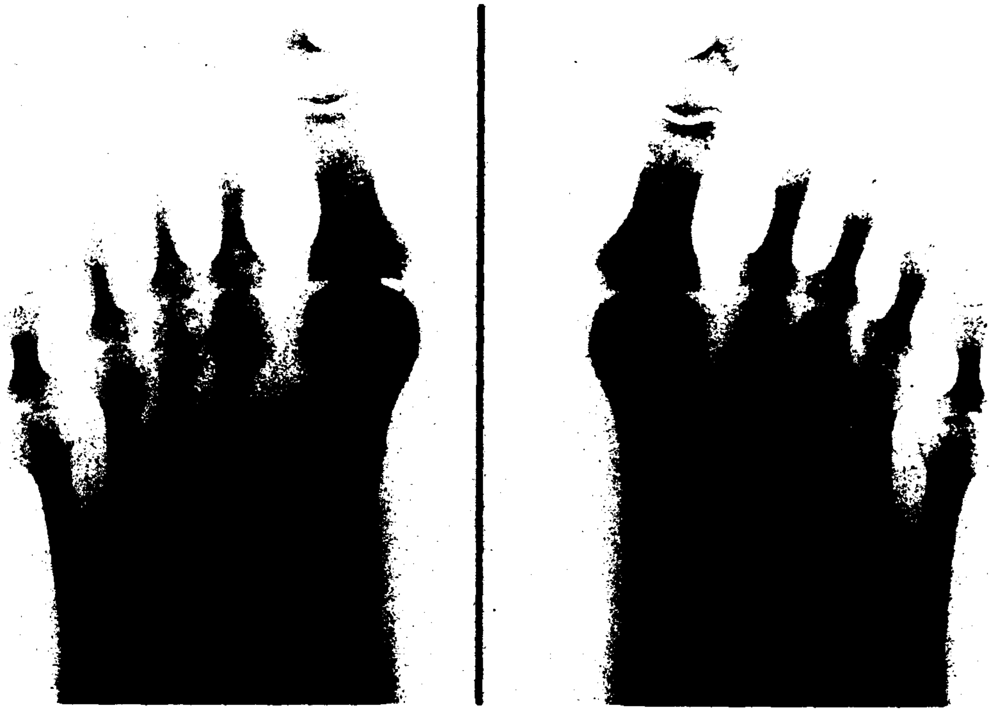


FIGURE 19.—Bilateral march fractures of metatarsal bones in different stages of healing. (Left) Anteroposterior roentgenogram showing fracture of third right metatarsal. (Right) Same, showing fracture of second left metatarsal. (Hullinger, C. W.: March Fractures. [Unpublished data.])

not complete because a periosteal buttress formed. If the buttress did not form, then a complete fracture was the rule, with displacement of the distal fragment laterally, the findings indicating the presence of a definite force acting in a constant direction. He was convinced, by these additional observations, that a march fracture, in its early stages, is a pseudofracture that should be included in the same category as pseudofractures caused by other nutritional states.

Other observers advanced different opinions of the mechanism of march fractures:

Meyerding and Pollock (*3*), in 1938, explained the periosteal proliferation present on the basis of constant irritation in imperfectly mobilized fractures subjected to the stress and strain of weight-bearing and motion. As a result of these forces, these observers postulated a gradual stripping of the periosteum; a collection of fluid from irritation at the site of the fracture; and, finally, the periosteal proliferation evident roentgenologically in most march fractures about 3 weeks after they occurred.

Barnes (*21*), in 1943, reported 20 march fractures observed during the training program at a Royal Air Force station. The finding of a periosteal reaction on the dorsomedial aspect of the shaft of the affected metatarsal in 16 of these cases suggested to him that the exciting force acts in such a manner as to bend the bone in an outward and downward direction. The result is both a periosteal tear and a cortical crack, first on the dorsomedial aspect.

FIGURE 20.—Bilateral march fractures of second metatarsal bones. Note that only subperiosteal callus shows in the roentgenograms. (Left) Anteroposterior roentgenogram of left foot. (Right) Same, of right foot. (Leavitt, D. G., and Woodward, H. W.: J. Bone & Joint Surg. 26: 733–742, October 1944.)

Colonel Hullinger and Major Tyler (*1*) advanced another explanation for the mechanism and healing of march fractures:

The incomplete fracture of a few of the bony trabeculations of the shaft of a bone is followed by hemorrhage, which is superficial and which, therefore, produces a periosteal elevation. New bone is formed in the hematoma, and calcium deposits occur early. If trauma is not eliminated—as it is not in undiagnosed or improperly diagnosed march fractures—fracture of additional bony trabeculations occurs, with additional hemorrhage, elevation of the periosteum, and osteogenesis. When trauma ceases, orderly healing and complete bony repair occur. The periosteal callus becomes dense and spindle-shaped, and new trabeculations traverse the fracture site.

If trauma is severe and repeated, these observers continue, the fracture is complete, and there may be slight displacement of the fragments. If trauma is less severe but is repeated over a period of several days, hemorrhage and small, incomplete disruptions of the bony trabeculations occur on each traumatic occasion, with subsequent profuse periosteal callus formation. Displacement is not the rule in march fractures, one reason, perhaps, being the protective splinting effect of the unaffected metatarsal bones.

Comminution is also not the rule in march fractures, though it was reported in a few oblique fractures, with 2–3 millimeter shortening of the metatarsal shaft (*16*), as well as in fractures of the femur (p. 167).

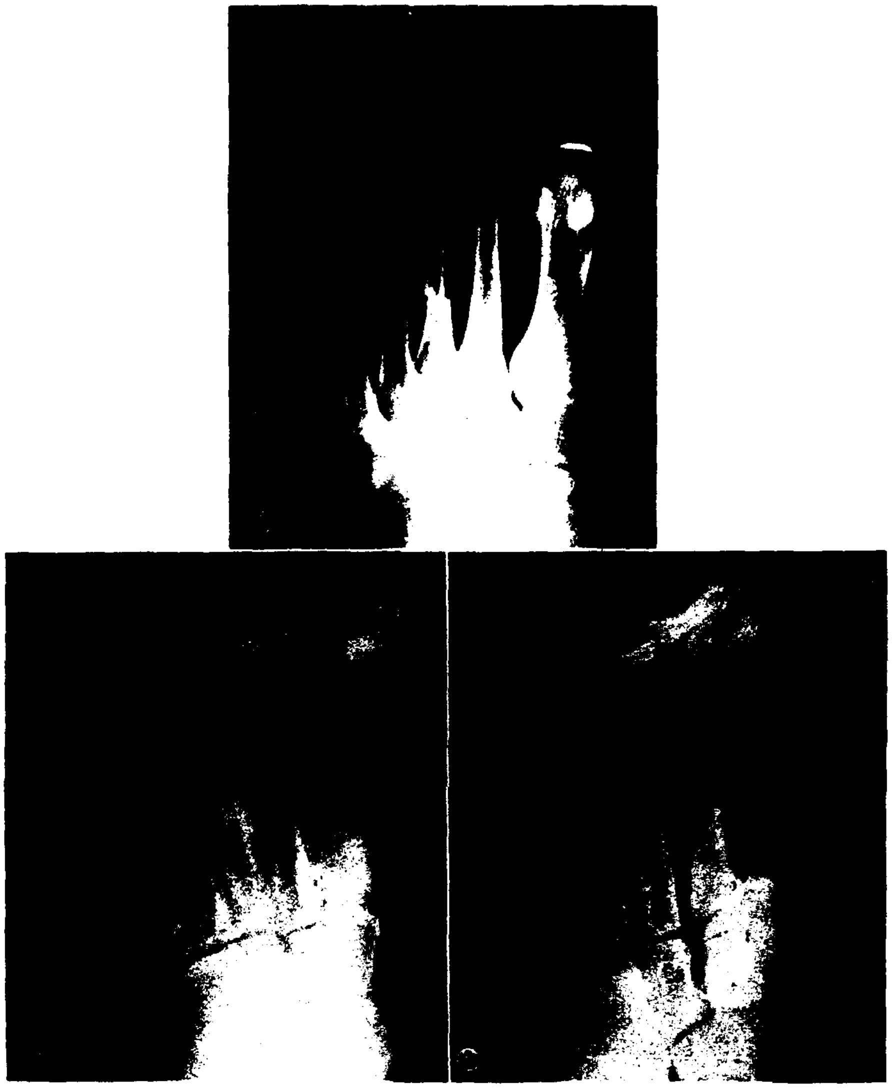


FIGURE 21.—March fractures of metatarsal bones in various stages of healing. A. Anteroposterior roentgenogram showing march fracture of third left metatarsal bone in early stage of healing. Note that fracture line is complete. Note also the displacement of the distal fragment. In many cases, the typical early sign of a march fracture is a slight periosteal reaction which increases in size as the process extends. B. Anteroposterior roentgenogram showing march fracture of third left metatarsal in intermediate stage of healing. Note complete fracture line and large amount of callus. This patient remained ambulatory. C. Oblique roentgenogram showing march fracture of third left metatarsal bone in late stage of healing. Note dense, spindle-shaped callus. This patient also remained ambulatory. (Van Demark, R. E., and McCarthy, P. V.: Radiology 46: 496–501, May 1946.)

ETIOLOGIC FACTORS

General Considerations

Investigation of the etiology of march fractures in World War II promptly eliminated certain factors:

1. The Camp Wheeler study (*1*) indicated that previous occupation played no special part in their development. In this series, the largest numbers of cases occurred in farmers, students, laborers, clerks, and machinists. In at least three of these groups (farmers, laborers, machinists), active movement or long standing was a part of the preceding life pattern, and it was concluded that, if a previous sedentary occupation played any part in march fractures, it was only a mild contributory factor, related to early fatigue.

2. The Camp Wheeler study also suggested that body weight played no part in the etiology of the fractures. The average weight of the men in this series was 158.16 pounds, and the largest number of fractures occurred in men weighing 140 pounds.

3. Foot deformities also seemed to play no significant part in the development of these fractures. The Bernstein group (*16*) found no correlation between them and such deformities as pes planus, pes cavus, or pronated feet. In the Camp Wheeler series, there were several instances of pes cavus, pes planus, and claw toes, but five of the six instances of third degree pes planus occurred in active athletes and one, in a professional ballplayer. In the U.S. Army reports, as in all other reports, most of the soldiers who sustained march fractures had perfectly normal feet. In the Camp Wheeler series, a number of men who sustained fractures had large central callosities or plantar warts underlying the metatarsal heads, but practically all of them were removed promptly from the line of march. All soldiers with foot deformities, in fact, who developed pain on extended use of their feet ordinarily fell out of the march before sustaining trauma sufficient to cause fractures.

4. Metabolic disturbances also seemed of small consequence in march fractures. Maseritz (*22*), before the war, had suggested that bony fragility might play a part and had proposed that more serious thought be given to calcium disturbances in their etiology. In the few cases studied from this standpoint during the war, no significant abnormalities were found. Colonel Tyner and Lieutenant Hileman (*18*), for instance, who studied the serum phosphatase, serum calcium, and fasting cevitamic acid in 12 of their patients, found all the values within normal range except for the serum phosphatase. The slight increase in these values (from 4.8 to 8.1 units by the modified Bodansky method) was interpreted as due probably to the stimulus of the healing fractures.

Structural Anomalies

In 1933, Dodd (*6*) advanced the theory that a relative shortening of the first metatarsal bone might be the cause of march fractures. He considered "march foot," as he termed it, a complication of subacute flat foot. According to his theory, it occurs in architecturally weak feet, in which muscular spasm and exhaustion alternate. As exhaustion supervenes, the stout ligaments of the foot are gradually stretched, and direct trauma to the bony skeleton occurs, the weakest bones being affected first. As the flat foot develops, the feet take up the position usual in this condition; that is, pointing outward instead of almost straight forward. The body weight, therefore, is no longer carried through a line passing between the first and second metatarsals parallel to their shafts and is no longer distributed squarely onto the five heads of the five metatarsals. Instead, it falls chiefly on the inside of the foot, in an oblique direction, chiefly on the first, second, and third metatarsals, and, to a lesser degree, on the fourth and fifth.

It seemed logical to Dodd, on the basis of this reasoning, to assume that, when the supporting power of the muscles and ligaments of the calf and foot was exhausted, the second metatarsal, and then the third, would fracture in that order. The theory is ingenious, but investigations made during World War II furnished no conclusive evidence to support it (*16, 18, 23*).

Trauma

Before the war ended, there was almost general agreement with the theory advanced by Colonel Hullinger and Major Tyler (*1*), that trauma is the exciting cause of all march fractures. The difference between this type of fracture and the ordinary fracture is that, in a march fracture, the trauma is slight and repeated rather than, as in the usual fracture, singular and more or less violent. The march fracture occurs because of physiologic weakness secondary to fatigue, which is brought on by increasing the weight of the load the soldier must carry and by forcing him to continue marching after he is fatigued. As fatigue increases, he marches relaxed and tired, with his muscles no longer in tone. Mechanically, therefore, his weight is borne by bones and ligaments, and, just as a wire will eventually break from repeated bending, so repeated "micromotion" of the bone leads to eventual fracture.

In the opinion of these observers, certain considerations rendered the soldier more liable to injury, including the early fatigue usual in certain psychiatric types, insufficient rest, overwork, poor musculature and weakness, and a disgruntled state of mind. The Camp Wheeler series revealed no significant variations in metatarsal length, width or spacing; in position and conformity of the sesamoid bones; or in the length, width, and general conformation of the feet. There was no essential difference in these respects

between 300 soldiers who had sustained march fractures and 300 individuals selected at random and similarly studied.

The theory of trauma as the cause of march fractures is clearly very reasonable. The trauma to which the foot of the infantry soldier was subjected in World War II was, as always, considerable. Added to his body weight was the weight of his equipment, which varied from 40 to 50 pounds and might exceed the upper limit in times of emergency.[2] Each foot had to sustain the man's own weight and the weight of his pack, plus the power applied to make 50 to 70 steps per minute, depending upon the rate of marching. The summation of these movements was that the metatarsals in, say, a 25-mile march, sustained approximately 25,000 upward and downward springing movements. This was sustained stress of a considerable degree.

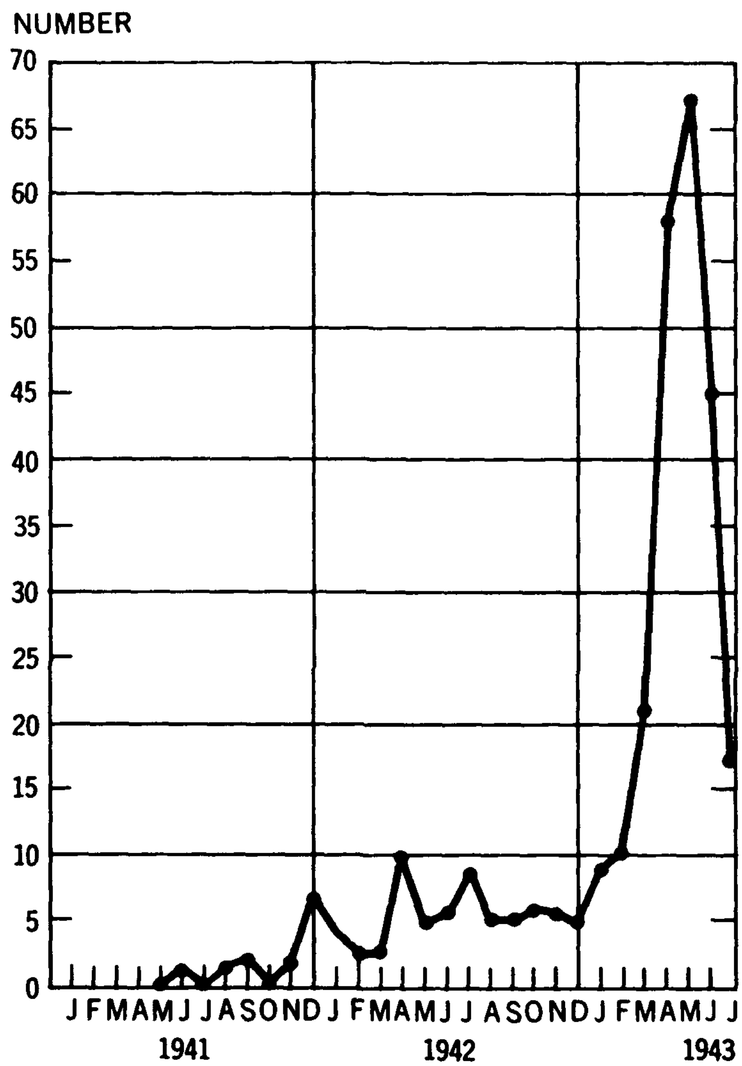
The entire program of infantry training in World War II was extremely strenuous. It was planned to condition troops physically, and to convert recruits into finished soldiers, as quickly as possible. The whole routine of life was infinitely more active and demanding than in almost any civilian type of endeavor. Such training, however, was essential to meet the requirements of modern war, and all the evidence went to prove that, when conditioning had been conducted properly, all structures of the body partook of its benefits. It was, therefore, reasonable to assume that tensile strength was added to the bones of the feet as well as to the muscles. There was no doubt that march fractures had a minimal incidence in properly conditioned troops (*5*).

Strong proof of the correctness of the Hullinger-Tyler theory that repeated trauma is responsible for march fractures was furnished by the events at Camp Wheeler (chart 1). Up to 1 May 1942, there had not been more than 10 march fractures per month. In March of that year, however, an order had bee issued that soldiers in training would carry rifles and full packs at all es, would proceed by foot from one area to another instead of riding, d frequently would move to adjacent areas on double time. Hospital admissions for march fractures rose steadily thereafter, and reached a monthly peak of 66 in May 1943. On 24 May 1943, the strenuous components of the training program were reduced, and while 24 patients with march fractures were admitted in June, only 17 were admitted in July. Further proof of the cause-and-effect relation of trauma and march fractures is that the number of these injuries always increased following the three periods in the training course in which large amounts of walking and marching were required.

The influence of trauma is evident also in a report by Major Nickerson (*20*). He observed 108 march fractures at Camp Fannin, Tex., where the terrain was rough and hilly, but none, in spite of a diligent search for them,

[2] There is a curious lack of official information about the weight of the infantryman's pack. The figures cited were obtained from questioning various informed persons. The pack for Medical Corps and Signal Corps personnel might weigh as much as 60 pounds, but members of these branches apparently were not susceptible to march fractures.

CHART 1.—*Variations in monthly admissions for march fractures to station hospital, Camp Wheeler, Ga., January 1942–July 1943*



Source: Hullinger, C. W., and Tyler, W. L.: Bull. U.S. Army M. Dept. 80: 72–80, September 1944.

at Camp Maxey or Camp Howze, Tex., where it was generally smooth. His explanation was that the terrain at Camp Fannin must have altered the mechanics of the foot so appreciably as to produce what amounted to an insufficiency disease. Contrary to the usual anatomic distribution of march fractures, the injuries in these 108 cases practically always involved the first metatarsal bone.

Major Childress (*7*) summarized the theory of trauma concisely and lucidly:

> March fracture is caused by repeated minimal trauma which, by its summation, causes an overloading of the functional capacity of an otherwise normal bone. That is, the functional demand is too great for the actual or inherent capacity of the bone. When muscles that act as shock absorbers for the bones and joints of the lower extremities become fatigued, they stretch, and the ordinary trauma incidental to weight-bearing directly affects the bones. The weakest area of the bone naturally responds most promptly. Repeated trauma increases the reaction, which may also be accelerated by whatever endocrine, neural, or circulatory disturbances may be present. Excessive or prolonged strain results in fatigue of the muscles and stretching of the ligaments that support the concavity of the metatarsal bones. The final result, as the individual walks, is that the weight falls heavily upon the unsupported heads of the second and third metatarsals, and repeated tension and trauma eventually produce a solution of continuity.

Experimental studies.—Experimental studies carried out at Camp Swift, Tex. (*24*), supported the theory of trauma:

> Observers here postulated minute bending of the metatarsals with each step during a march, the eventual response to prolonged intermittent stress being a molecular rearrangement of the regional calcium phosphate. As a result, the bone becomes brittle and finally fractures, just as, under prolonged variable stress, steel crystallizes and eventually fractures.
>
> In an endeavor to prove this theory (the so-called microtraumatism of European authors), these observers studied the effect of stress on metatarsals secured from fresh cadavers. The ends of the bones were mounted firmly between wooden blocks, and force was applied at right angles to the shaft in the area just proximal to the metatarsal neck. A weight of 50 pounds produced a bowing of approximately 1.5 millimeters, though it was thought unlikely that bending of such a degree occurs in the living subject. Weight was then added over the area tested until, at 160 pounds, a fracture of the third metatarsal occurred, with a loud snap. The fracture was transverse and was located about half an inch proximal to the neck of the bone, which is the clinical location of most march fractures.

The role of muscles.—The Camp Wolters observers, while accepting the theory of summation of trauma as the cause of march fractures, also emphasized the possible role of muscles (*18*). Bones not adequately supported by muscles, they pointed out, cannot tolerate great stress. They considered it significant that, when they were questioned on this point, most soldiers admitted that they had been aware of muscle fatigue before the pain occurred that heralded the advent of a march fracture. Muscle fatigue was particularly evident when the march was over rough ground or when a heavy load was carried. Major Nickerson (*20*) also accepted the role of

muscles in the production of march fractures, but believed that it was exerted by way of a nutritional change and was not directly mechanical.

Overseas experiences.—Very few march fractures were reported from theaters of operations. An experience in the China-Burma-India theater, however, provided significant etiologic data to support the theory of repeated trauma as a cause of these fractures.

This report, by Captain Donald and Captain Fitts (*5*), has already been cited. The troops involved, the Mars Task Force, composed of two brigades, left their training area near Myitkyina for a forced march of some 300 miles to the Burma Road. Almost at once, typical march fractures began to occur; 60 casualties were received at one hospital and at least 20 others, in neighboring installations. Eight months earlier, Merrill's Marauders had marched up the Stilwell Road and into the Hukawng Valley, a mission comparable in distance and terrain to that undertaken by the Mars Task Force. This force sustained only two march fractures; both of these casualties were received in the hospital which later received 60 casualties from the Mars Task Force.

These 60 casualties were studied intensively, both individually and in comparison with 60 controls from the medical wards of the hospital who met three criteria: (1) They had completed at least 200 miles of the forced march undertaken by the Mars Task Force, (2) they had no foot complaints of any kind, and (3) they had no diseases involving the musculoskeletal system.

The average march fracture casualty was a 25-year-old white soldier, 5 feet 9 inches tall, weighing 157 pounds, and carrying a 57-pound load. Symptoms were noted, on an average, on the 13th day of the march, after 106 miles had been traversed. About a third of the men had associated lesions of the unfractured extremity, in the form of blisters, sprains, or contusions, lesions which, it was thought, placed an added burden on the foot subsequently fractured.

There were no significant differences between these casualties and the control group in respect to age, height, body weight, weight of load, previous occupation, previous history of foot troubles, or type of shoe worn. There were also no significant differences in these respects between these casualties from the Mars Task Force and the soldiers who made up Merrill's Marauders. There were, however, significant differences in the adequacy of foot training in preparation for the missions between the control group and the casualties with march fractures. A minimum of two hikes per week, of over 40 miles each, just before the march, was set up as an adequate criterion for evaluation of adequacy of training. It was found that 51 percent of the soldiers in the control group had met this standard against only 18 percent of those who developed fractures. The conditioning of the control group before it left the Zone of Interior had also been superior, though it was realized that the benefits from it might have been somewhat vitiated during the long sea voyage.

A comparison of the incidence of fractures in the two brigades that made up the Mars Task Force also provided significant data. Both units had approximately the same number of men. Both had made roughly identical marches. But before the expedition, one unit had been required to march to and from field maneuvers and had had, in general, a more rigorous training in respect to use of their feet than the other brigade had had. The incidence of march fractures in the unit with less rigorous training was five times that of the other brigade.

Proper conditioning was also assumed to explain, in part, the low incidence of march fractures among Merrill's Marauders. Many soldiers in this force had been in previous campaigns requiring vigorous marching, and the entire outfit had had superb conditioning during the weeks immediately preceding the march up the Stilwell Road.

Fifteen men in the Mars Task Force fracture group, against 10 in the control group, had histories of previous foot difficulties, but the disproportion was not regarded

as significant. Examination in the hospital showed a much larger proportion of the fracture group with static foot disorders, but analysis of the cases made it seem probable that these troubles might not have been present before the march and might, instead, have been produced by overloading inadequately conditioned feet.

From their clinical and roentgenologic observations, Captain Donald and Captain Fitts concluded that march fracture occurs as a result of functional overloading of a structurally inadequate and improperly conditioned foot. They noted that, in spite of the large numbers of Chinese casualties evacuated to the U.S. Army installations from units which made the same march as the Mars Task Force, no march fractures were encountered in soldiers of this race. The fact that Chinese soldiers were accustomed to more strenuous foot activity than were U.S. Army troops was regarded as possible further proof of the role played by inadequate conditioning in the production of march fractures.

In curious contrast to the march fractures encountered in the Mars Task Force, no fractures were recorded in the extensive studies made in the 29th Infantry Division in England in the fall of 1942, when strenuous training marches were first undertaken on hard-surfaced roads (*25*). The complaints of pain and fatigue in the lower extremities so far exceeded expectancy that a detailed investigation was undertaken. In the group of 820 soldiers examined because of complaints of foot disability, only 20 had entirely normal feet. In seven cases, the trouble could be traced to poorly fitted shoes. In all the remaining cases, there was objective evidence for the complaints, but march fractures were not among the conditions listed.

The experience just related is similar to that reported by Maj. Bernard T. Daniels, MC, and Maj. Charles H. Wilson, MC (*26*), in a survey of marching efficiency in four officers' training classes, involving 3,696 men, at the Medical Field Service School, Carlisle Barracks, Pa., early in 1944. About a third of the 71 casualties were caused by foot troubles, but march fracture was not included in the list of causes. One wonders whether a followup study of this group, with repeated roentgenograms, and of the group investigated in England might not have revealed march fractures in some of the men with foot disabilities.

CLINICAL PICTURE

The clinical picture in most march fractures observed in World War II was strikingly similar. While the onset of symptoms was usually insidious, it was sometimes so abrupt and acute that the soldier could tell the exact time at which he became aware of the injury. An abrupt onset was characteristic of the cases just described from the China-Burma-India theater. About half of the men could fix the exact time of onset (they described the pain as unlike any they had experienced on any previous march), and the others could fix it within 6 hours.

Many of the men in the Zone of Interior, when they first sought medical advice, were able to recall that their first awareness of pain followed a long march with a full pack. The pain was aching and burning, very annoying, but seldom sufficiently severe at the onset to require immediate withdrawal from the line of march, though eventually walking became impossible. Many of the soldiers in the China-Burma-India theater continued to march

for an average of 5 days, over a distance of 37 miles; the pain was perhaps more endurable because the region, except in certain areas, was too dangerous for dropouts.

The original pain was relieved completely by rest but recurred when activity was resumed, particularly if continued weight-bearing was necessary. It increased gradually in intensity and severity as the causative trauma was repeated. While it was localized usually to the involved area, it might extend to the rest of the forefoot or to the posterior aspect of the foot. The man began to walk with a limp, and, if the second or third metatarsal was affected, he tended to walk on the outer side of the foot. He found it difficult or impossible to stand with the weight on the ball of the foot.

Other symptoms included stiffness of the toes, due to spasm of the interosseous muscles, and rigidity of the forefoot, which was inverted or everted, depending upon the particular metatarsal fractured.

When the foot was examined, many of the patients could place their fingers directly over the fracture site. If they could not, there was practically always point tenderness over the fracture site as well as on pressure on the head of the bone with the toe dorsiflexed. In most cases, there was pain on flexion or manipulation of the injured bone. Pain was complained of also if the examiner attempted to manipulate the metatarsal area or to flex or otherwise manipulate the affected bone. Percussion over the tip of the extended toe elicited a complaint of pain if the fracture of the metatarsal was complete. Motion in the ankle joint and in the uninvolved part of the foot was free and painless. Bony crepitus was most unusual.

In two of the cases reported by Stammers (*27*), tenderness was felt in the interosseous space rather than over the bone. The probable explanation was tearing of the periosteal nerve, with the pain referred back to the interosseous nerve, which it joins.

Shortly after the onset of pain, a localized swelling of the soft tissues appeared. It was not pronounced at the fracture site and tended to obliterate the spaces normally present between the extensor tendons. Sometimes, it extended to the plantar, as well as to the dorsal, aspect of the foot. The edema sometimes was slightly pitting. In early cases, it disappeared overnight with rest, but promptly reappeared with activity. In advanced cases, the skin was shiny and tense, with localized heat and some redness occasionally reported. In two of the cases recorded by Meyerding and Pollock (*3*), there was definite erythema over the dorsum of the foot, but the ecchymosis present in the usual traumatic fracture because of injuries of the soft parts naturally was not present in a march fracture.

At the end of a week, and sometimes as late as 2 or 3 weeks, after the appearance of the swelling, a hard mass was palpable over the injured bone.

DIAGNOSIS

March fracture should have been the first diagnostic possibility thought of in any soldier who complained, after a long march, of pain in the foot accompanied by swelling of the dorsum. It was frequently not thought of at all, which might have been expected because of lack of civilian experience with the condition. Captain Donald and Captain Fitts (*5*) regarded the clinical history and physical findings as so characteristic that, when fractures were seen early, they found it easier to make the diagnosis on these points than on roentgenologic evidence. On the other hand, Stammers (*27*) emphasized that, if he had conceived of march fracture only as a spontaneous fracture that occurs during prolonged marching, he would have missed the diagnosis in two of his three cases.

Roentgenologic examination.—Roentgenologic examination was seldom made early in march fractures observed in World War II because the patients were seldom seen until some time had elapsed after injury. When roentgenograms were made early, they were frequently negative. In such cases, if the pain persisted and the examination was repeated after a lapse of several days, the films were likely to be positive.

It is easy to explain why findings were frequently negative in early roentgenograms. There was usually no displacement, and the fracture, because of the structure of the injured bone, extended only a relatively short distance in any single plane. As a result, X-rays coming from a single plane could pass through the fracture line only in that plane. A fracture line that extended through the cortex could, of course, be seen at any time after the injury.

It was generally agreed that roentgenograms of march fractures must include both dorsoplantar and lateral oblique projections and that their technical qualities must be flawless. The lateral oblique view was the more important, since it frequently revealed a minute fracture line or a slight subperiosteal calcification not evident in the dorsoplantar view. The film frequently had to be held at various angles to modify the intensity of the illumination (*3*); otherwise, too brilliant light might mask the hairline shadow of the fracture.

In 1933, J. S. Speed and Blake (*28*) described five roentgenologic stages of march fracture as follows:

1. Roentgenograms taken soon after the onset of symptoms show only swelling of soft tissues, with no bone changes.
2. At the end of 1 to 3 weeks after the injury, there is slight periosteal fuzziness at the site of the fracture, which presents as a minute line. Occasionally, the fracture is evident before the reaction occurs.
3. A little later, the periosteal shadow becomes circumscribed and is more distinct. The fracture, which is not usually distinct, has an irregular outline, and the callus is overabundant for the size of the bone and of the fracture.
4. The fracture shows signs of union. The callus, which is denser, is now well

circumscribed and is spindle-shaped. At this stage, as well as in the preceding stage, the diagnosis of sarcoma seems possible.

5. At the end of 6 months, solid union is evident, and excess callus has been absorbed. The shaft of the bone is normal except for a small amount of residual cortical thickening.

Major Nickerson (*20*), who made a particular effort to demonstrate early march fractures, described four roentgenologic stages as follows:

1. The first evidence of the fracture is a fuzzy periosteal reaction along the medial aspect of the shaft of the affected bone.
2. A partial, incomplete break is evident through the lateral cortical thickness.
3. The periosteal reaction on the medial aspect of the bone has become more pronounced. The outer layers of the lateral cortex have parted, suggesting that they have burst in that direction, while other layers show changes that indicate, in addition, a minute internal collapse with minute overriding. In some instances, some chips are sheared off the proximal cortex.
4. Condensation of the periosteal proliferation with maturation into normal callus now obscures all finer roentgenologic details.

A number of observers regarded roentgenograms as useful only if they were made serially (*29*). Their opinion was that, in all of these injuries, there was dissolution in the continuity of the shaft of the bone even if no fracture line could be seen.

Differential diagnosis.—At one time or another, the following conditions had to be considered in the differential diagnosis of these fractures:

1. Cellulitis, which was ruled out by the history and by the absence of signs of true inflammation.
2. Contusions, strains, and sprains, which were ruled out by the history and the physical findings.
3. Skin infections, such as dermatophytoses, which were ruled out by the physical findings.
4. Tenosynovitis and osteomyelitis, which were ruled out by the absence of signs of true inflammation, and, in osteomyelitis, by roentgenologic examination.
5. *Luetic periostitis, which was ruled out by the history and by serologic studies.*
6. New growth, particularly sarcoma. The metatarsal bones are not a common site for osteogenic sarcoma, and the history and roentgenologic findings were usually sufficient to exclude it; in the occasional case, biopsy was necessary, and the pathologic process thus revealed, in more than one instance, prevented the amputation that had been advised. Two such cases have already been cited (*6*, *19*). In another case, Maj. (later Lt. Col.) George R. Krause, MC (*30*), advised a differential therapeutic test; namely, the application of a cast for 3 weeks. If the lesion was a neoplasm, the spindle would be of the same size or somewhat larger at the end of this period. If the lesion was a march fracture—as it was proved to be in the case in question—the callus at the end of this time would be smaller, denser, and more circumscribed than it was originally.

MANAGEMENT

Plaster.—The original treatment for march fractures consisted of the use of some type of plaster cast, which usually extended from the tip of the

toes to the upper third of the leg. It was well molded over the plantar surface of the foot and around the heel and malleoli. Sometimes, a walking iron was incorporated. The cast was removed at the end of 4 to 6 weeks, depending upon the roentgenologic findings, and physical therapy was carried out for another week or two before return to full duty was permitted.

Rest and crutches.—In some cases observed in World War II, results obtained by simple bed rest were as good as, or better than, those achieved by plaster immobilization. In other instances, crutches were used for 4 weeks to avoid weight-bearing, and a week or more of ambulation without them was required before return to duty was recommended. The precise duration of treatment depended upon the severity of symptoms and the time at which the patients were first observed. At the regional hospital at Camp Swift, which served a large training area (*24, 31*), it was found that, when weight-bearing was restricted for a month, the fractures healed without excessive callus, and less than 1 percent of the men without previous symptoms from some structural irregularity of the foot complained of any residual symptoms. By this method, 48 of 53 patients in the Camp Swift series were returned to full duty.

In an occasional case treated by a walking cast, callus formation was excessive and caused pain in the affected area because of pressure between the callus and the sole of the shoe. When only crutches were used, without weight-bearing, the callus was less exuberant.

Modification of shoes.—In 1944, Colonel Bernstein and Maj. Joseph R. Stone, MC (*32*), in a report of 307 fractures from Camp Wolters, described a method of management which eventually was applied in 634 of the 692 fractures which made up the total series from this post (*16*). Men with march fractures, they reasoned, suffered pain during the pushoff phase of ambulation; that is, when the toes were dorsiflexed, the heel was off the ground, and the body weight was borne on the heads of the first, second, and fifth metatarsals. The pain was lessened if the foot was held rigid during ambulation, so that motion at the metatarsophalangeal joint did not occur.

To produce the desired rigidity, these observers devised a steel bar, 6 inches long, one-half to five-eighths of an inch wide, and one-eighth of an inch thick, to be countersunk into the sole of the shoe (fig. 22). The bar originally was incorporated on the weight-bearing surface of the sole, but it was found that, as the sole wore down, the metal began to protrude and caused discomfort by acting as a rocker. The bar, therefore, was countersunk on the underside or non-weight-bearing surface of the sole, where it was held in position by four rivets. Later, because of material shortages, three of the four rivets were replaced by tacks. A felt pad was sometimes placed along the longitudinal arch, to redistribute the weight. The bar was left in place for 4 or 5 weeks, until solid healing of the fracture was assured. The same bar could be used again and again.

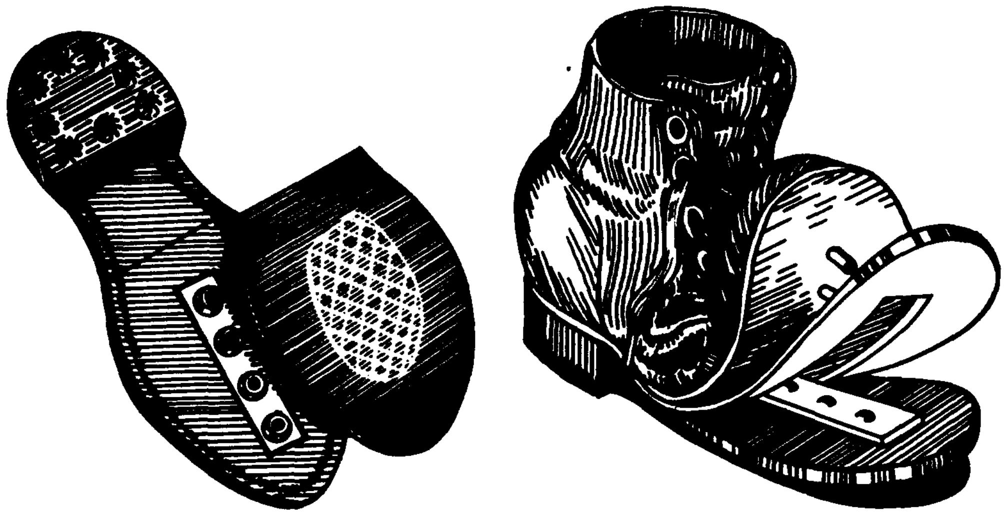


FIGURE 22.—Modified shoe used in treatment of march fractures to hold foot rigid during pushoff phase of gait. (Left) Underside of shoe showing steel bar countersunk into sole on non-weight-bearing surface, between inner and outer soles. (Right) Sole of shoe separated to show countersunk bar and rivets holding it in place. (Bernstein, A., and Stone, J. R.: J. Bone & Joint Surg. 26: 743–750, October 1944.)

With this method, hospitalization was not required. A man with a march fracture was simply sent to the camp shoe repair shop to have the bar placed in his shoe and was returned to full duty as soon as the correction had been made. Obviously, this was a logical technique because in a march fracture, there is seldom any loss of position or of alinement and, therefore, no necessity for immobilization in plaster.

RESULTS

The element of loss of time necessarily entered into consideration in the management of march fractures, and from this standpoint, the results of treatment were sometimes highly dubious. Captain Donald and Captain Fitts (*5*) called attention to the serious manpower losses troops were suffering in a combat zone from a relatively trivial and superficially unimportant injury. They immobilized their patients in plaster with an attached walking iron for 5 to 6 weeks, the duration of immobilization depending upon roentgenologic evidence of bony union. At the end of 5 months of observation, there was good clinical and roentgenologic evidence of bony union in every instance, but only 30 of the 60 men affected had been returned to duty, and it was thought that 15 of the 30 still hospitalized probably would require reassignment to noncombat duty.

Other reports indicated similarly heavy manpower losses. Maj. Louis W. Breck, MC, and Col. Norman L. Higinbotham, MC (*24*), treated their 54 patients on an average of 35 days each; this was a loss, quite aside from

possible end results, of about 5 manpower years. In the first series of march fractures (313 injuries in 300 men) reported from Camp Wheeler (*1*), 274 patients were treated in plaster for an average of 32.75 days each, a loss of about 24½ manpower years.

These were enormous and intolerable losses, the more intolerable because it was doubtful that they represented the total losses. It was often noted that soldiers who had suffered march fractures were no longer good infantrymen because they had lost their ability to walk long distances. Maj. Darrell G. Leavitt, MC, and Maj. Harry W. Woodward, MC (*23*), were particularly pessimistic about the end results of treatment. They used plaster casts for 6 weeks, followed by gradual weight-bearing, and, at the end of 7 months, found only 10 of their 47 patients completely recovered. The remainder complained of pains of various sorts in the feet, swelling, and limping when hiking or any similar stress was put upon them.

These surgeons, in view of their own dubious results, wondered whether reports of good results achieved by plaster might not be accounted for by an insufficient followup. Their own followup of a new method of treatment was not long enough to permit its evaluation. Its components depended upon the time at which the man was seen. If the fracture was less than 2 weeks old, plaster was employed for 3 weeks, followed by warm whirlpool baths, massage, and prohibition of weight-bearing until soreness had entirely disappeared. Vitamins were used empirically. If the fracture had occurred more than 2 weeks previously, plaster was dispensed with and the other methods listed were used at once.

Colonel Bernstein and his associates (*16, 32*) used the shoe correction method in 634 of their 692 march fractures, with remarkable results: Every man in the group was able to complete his basic training. It was estimated, using 56 hours of duty per week and the minimum of 6 weeks usually required for healing of a march fracture, that over a 14-month period, this method had saved 336 training hours per man, a grand total of 213,024 training hours, or 73 training years.

In addition to the savings of manpower it effected, this method had other advantages. The atrophy of bone and muscle usually present when a cast is worn did not occur, and there was, therefore, no necessity for physiotherapy, as there usually is when a cast is removed.

The results achieved at Camp Wolters were related to the time at which the Bernstein-Stone bar was applied. In three cases in which a period of 17 days had elapsed from injury to application of the bar, full recovery required 71 days. In four cases in which the timelag was 14 days, 73 days were required. When, on the other hand, the bar was applied within 24 hours of injury, as it was in 68 cases, the period of convalescence was reduced to 47 days; and when it was applied within a few hours, as it was in 151 cases, convalescence occupied between 25 and 35 days.

Although similar sequelae undoubtedly occurred in other series of cases, only the Camp Wheeler reports went into any detail on the matter

(*1*). In the first series reported, 16 of 313 patients had enough complaints after discharge to require a second hospital admission. Eleven patients complained of pain and swelling although roentgenograms showed only excessive callus in the healed fracture. All of the men in this group had been seen late, after callus had already formed, or had been treated in molded casts, without immobilization. One patient who was readmitted, whose injury was complicated by a Sudeck-like osteoporosis, required 163 days of hospitalization before he was discharged from the Army; he was over 40 years of age. Another, who eventually was returned to full duty, required 176 days of hospitalization for lymphedema. Both of these patients were treated by lumbar sympathetic injections of Novocain (procaine hydrochloride).

The other five patients in this group were readmitted with fresh march fractures and should not properly be listed among patients with true sequelae of the original injuries.

PREVENTION

The trouble with practically all of the suggestions advanced for the prevention of march fracture was that they were utterly impractical in military life. This was true, for instance, of the elaborate system proposed by Dodd (*6*), who believed that structural weakness of the foot was the responsible factor.

Major Nickerson (*20*) based his proposal for certain modifications in the shoes of newly inducted soldiers on his own theory of local metabolic inadequacy, with consequent skeletal changes that rendered the bones more friable and, therefore, more susceptible to fracture. Meyerding and Pollock (*3*) emphasized the possible role of large, badly fitted shoes, which did not support the forepart of the foot, and it goes without saying that shoes of this kind, or any other badly fitted shoes, are undesirable under any circumstances.

It is doubtful, however, that changes in shoes would have prevented march fractures. None of the evidence suggests that footgear played any significant part in their etiology. The U.S. soldier in World War II was, on the whole, extremely well shod (p. 781). His shoes were not always carefully fitted, but when they were not, he himself was likely to complain about them before any great harm was done. It is doubtful, except for the general principle that shoes should be of the proper type and accurately fitted, that prophylaxis from this standpoint would greatly reduce the number of march fractures.

Major Leavitt and Major Woodward (*23*) raised the point that the suppleness (so-called rocker curve) assumed in the shank and forepart of the army shoe after it had been worn for some time in training might not be desirable. This flexibility did permit a good deal of dorsiflexion at the metatarsophalangeal joints, particularly when a heavy pack was carried,

but no one else seems to have commented on this flexibility or objected to it.

All the evidence, on the other hand, points to the importance of proper training and conditioning. Peak training should not be attained abruptly if it is possible to attain it more gradually, though it is recognized that military circumstances do not always permit the slower approach. Adequate training, however, is essential. As the China-Burma-India theater experience (*5*) clearly shows, soldiers overseas could stand up under long marches over difficult terrain without sustaining this type of injury entirely in proportion to the excellence of their training and conditioning.

All the evidence also indicates that the seriousness of march fractures, in terms of time lost from duty, can be greatly reduced by their prompt recognition. This fact implies routine roentgenologic examination of all soldiers who complain of foot disabilities not clearly due to other causes, with repetition of the examination if the original film is negative and symptoms persist.

It would seem, too, that the time lost from duty in march fractures would be greatly reduced if treatment were routinely by the Bernstein-Stone bar (*32*). One soldier, for instance, fractured his second left metatarsal on the 39th day of training, the second right metatarsal on the 43d day, and the third right metatarsal on the 44th day. Yet, he was able, after treatment with the Bernstein-Stone bar, to complete his basic training and qualify for full infantry duty.

MARCH FRACTURES IN OTHER SITES

While the overwhelming number of march fractures occur in the metatarsal bones, these injuries occur in other bones of the foot and also in other bones, including the tibia and fibula, the femur, the pelvis, and the ribs.

Os Calcis

There were 71 march fractures of the os calcis, 18 bilateral, in the 53 men with injuries of this kind observed at Camp Wheeler between 1 July 1943 and 1 February 1944 (*14*). Similar injuries were suspected in 27 other men, but, because of their separation from service or change of station, the diagnosis could not be proved. In the final cumulative report from Camp Wheeler (*15*), there were 222 march fractures of the os calcis, 64 of which were bilateral. One of the fractures observed in the China-Burma-India theater (*5*) was also bilateral.

In all instances, the onset was insidious and followed repeated, extensive, minimal trauma to the heels as the result of walking, marching, jumping over barriers on obstacle courses, jumping ditches on cross-country runs, and other exercises in which jumping was necessary and the heels

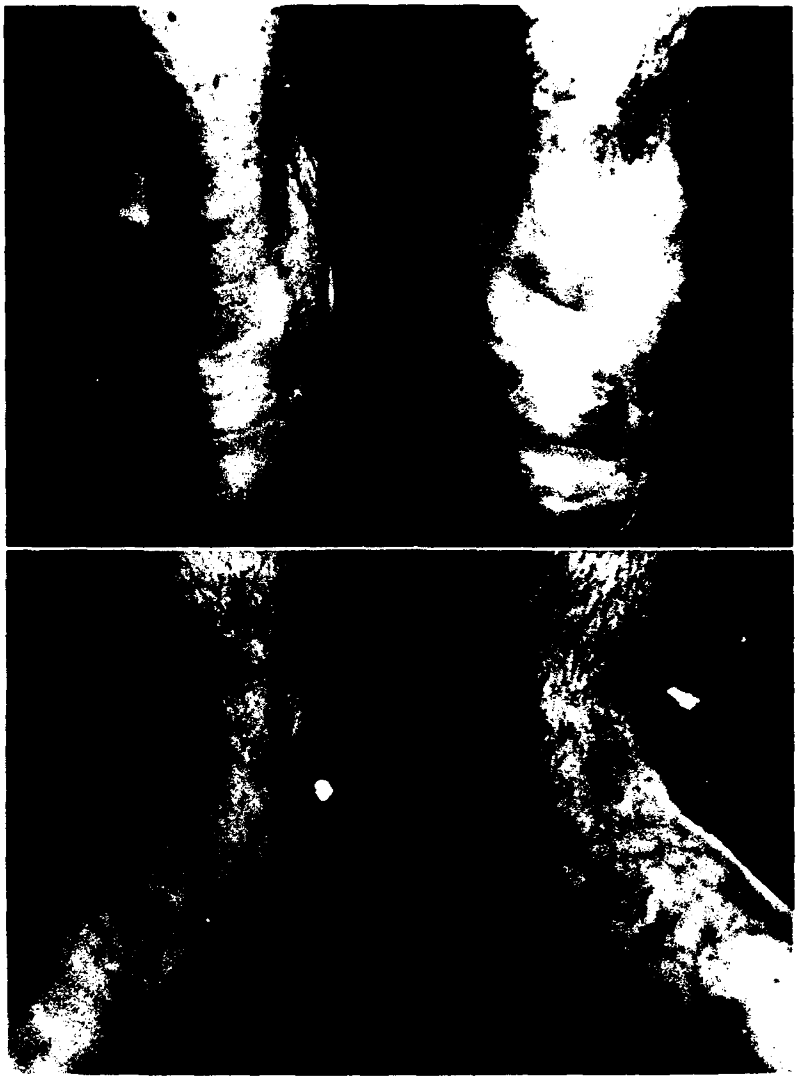


FIGURE 23.—March fracture of right os calcis. (Top) Posterior view. Note the diffuse swelling on the right foot over the lateral and medial surfaces of the calcaneus, extending up to the malleoli. This swelling, which the patient stated had been worse on several previous occasions before hospitalization, disappeared completely after 8 days' rest. The left foot is normal. (Bottom) Anterior view. Note fullness under medial malleolus on right foot. The left foot is normal. Roentgenograms made when these pictures were taken (3 weeks after admission to the hospital) showed a healing line of calcified callus in the calcaneus. (Hullinger, C. W.: J. Bone & Joint Surg. 26: 751–757, October 1944.)

were subjected to trauma. Many soldiers first experienced pain following cross-country runs over a 2-mile course in which the requirement was to run 100 yards; walk 100 yards; run 200 yards; walk 100 yards; run 300

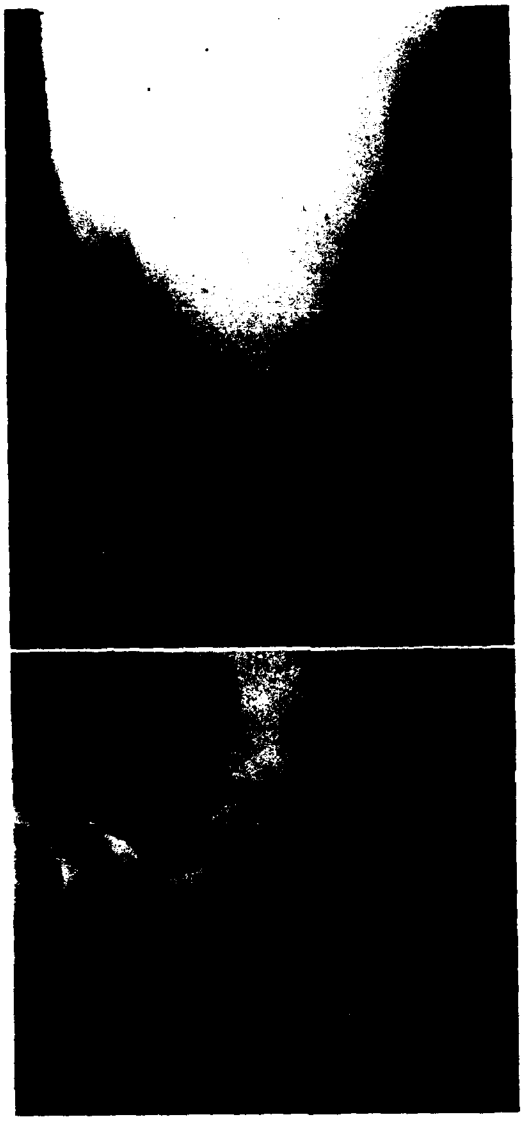


FIGURE 24.—March fracture of left os calcis. (Top) Anteroposterior roentgenogram showing bandlike area of condensation extending about waist of bone. Note callus formation and piling up of periosteal bone in periphery. (Bottom) Lateral roentgenogram. (Van Demark, R. E., and McCarthy, P. V.: Radiology 46: 496–501, May 1946.)

yards; walk 100 yards; and then repeat the cycle until the 2-mile course was completed.

The chief symptom was pain in the heel (heels), which gradually increased and eventually caused limping. When the soldier reported to sick

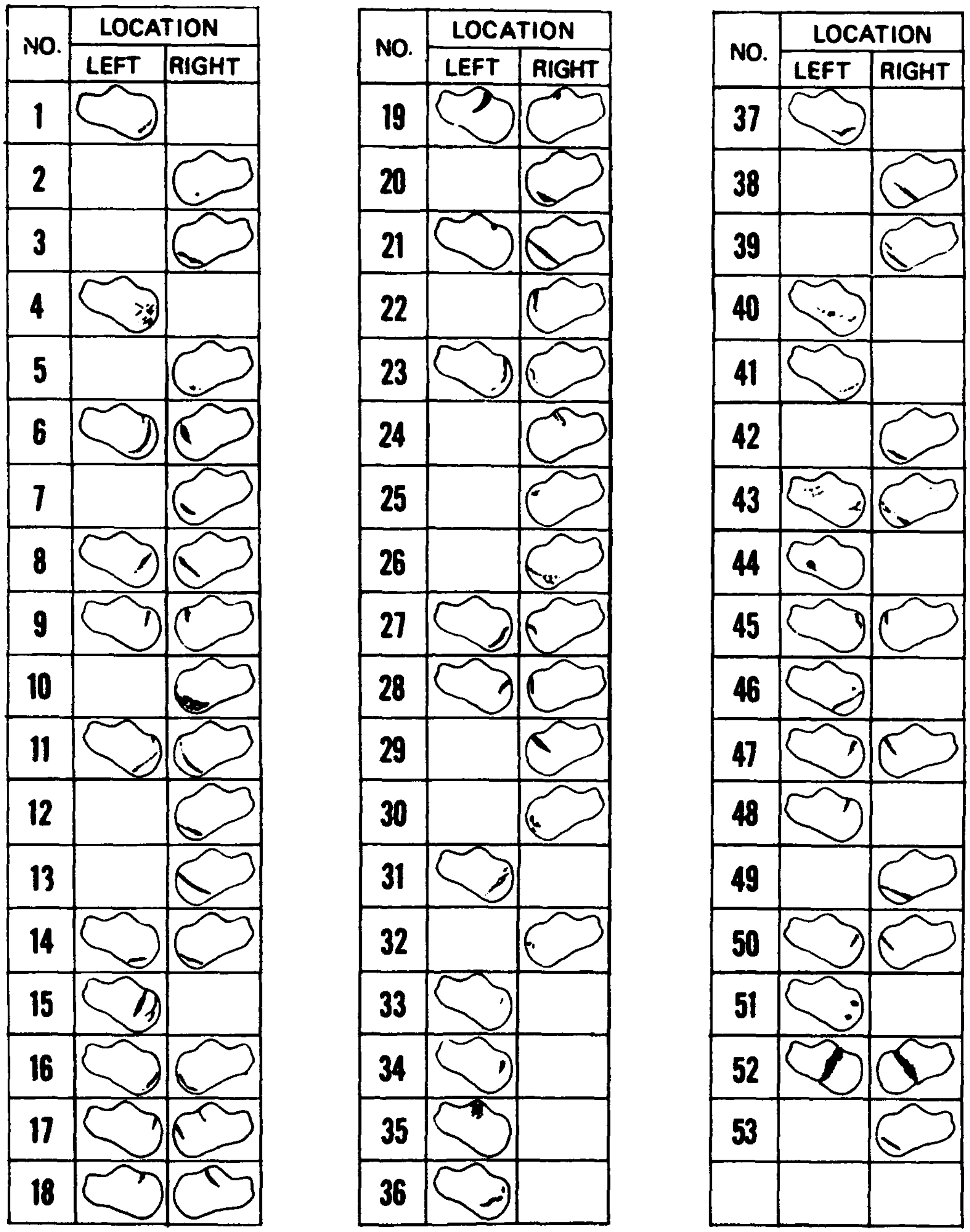


Figure 25.—Schematic showing of location of callus in 53 march fractures of the calcaneus. The drawings were made from roentgenograms taken during the healing stage. (Hullinger, C. W.: J. Bone & Joint Surg. 26: 751–757, October 1944.)

call, usually at the end of 1 or 2 weeks after the onset of pain, examination revealed a moderate, diffuse swelling of the soft tissues over the medial and lateral aspects of the calcaneus (fig. 23). The swelling usually faded out anteriorly over the midtarsal region, but extended superiorly and frequently obliterated the bony landmarks of the malleoli. The edema was

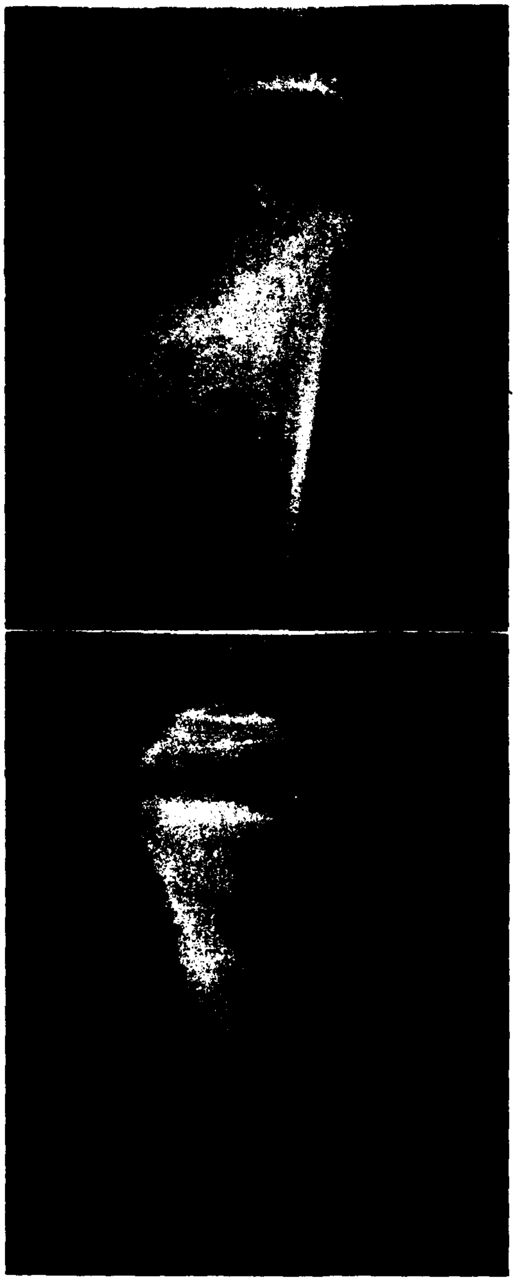


FIGURE 26.—March fracture of upper shaft of left tibia. (Top) Anteroposterior roentgenogram. Note that fracture line appears complete, that there is no displacement, and that callus is abundant. (Bottom) Lateral roentgenogram. (Van Demark, R. E., and McCarthy, P. V.: Radiology 46: 496–501, May 1946.)

FIGURE 27.—Healing march fracture of right tibia. (Left) Anteroposterior roentgenogram. (Right) Lateral roentgenogram. (Hullinger, C. W.: March Fractures. [Unpublished data.])

occasionally of the pitting variety. There was no evidence of hemorrhage and the lesion had none of the characteristics of a contusion.

The swelling disappeared promptly after several days of bed rest, but recurred with equal promptness when activity was resumed. The presumptive explanation was an increase in the extracellular and intracellular fluids poured out in response to autonomic stimuli arising within the bone.

Tenderness was elicited by compression of the calcaneus between the thumb and fingers. It persisted for several weeks, even after swelling had disappeared.

Pain was elicited by ballottement of the inferior or posterior surface of the heel. Stretching of the heel cord by dorsiflexion of the foot seldom produced discomfort, and walking on the toes caused less pain than normal walking.

An associated tenosynovitis frequently involved the Achilles tendon, the tibialis anterior tendon, or both, and the symptoms that arose from this

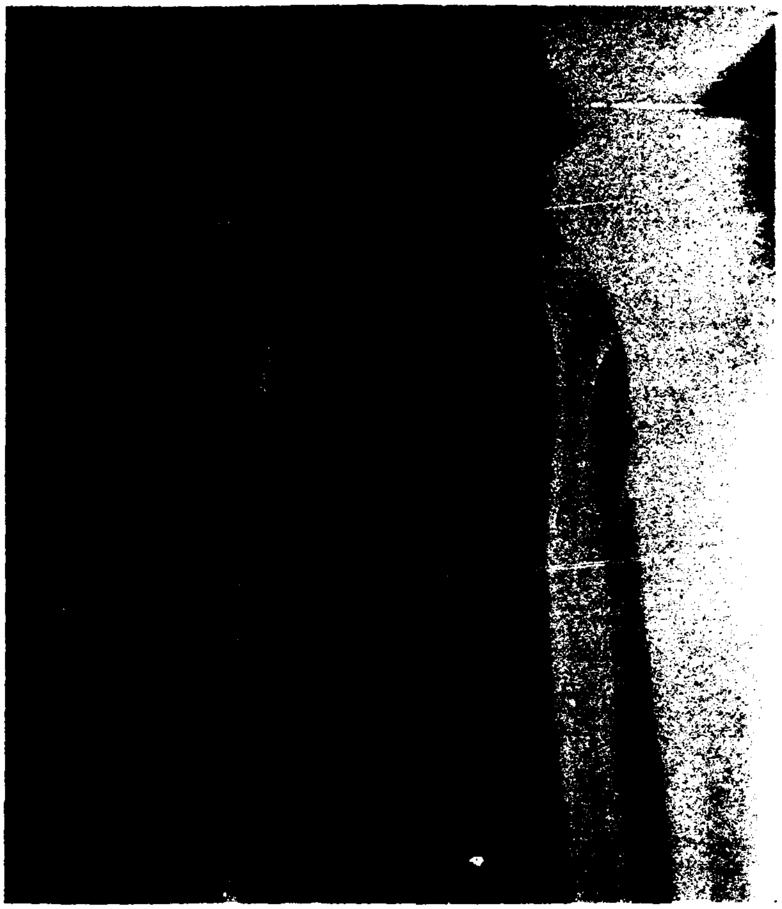


FIGURE 28.—Typical example of march fracture of medial aspect of left tibia in healing phase. (Left) Anteroposterior roentgenogram. (Right) Lateral roentgenogram. (Robin, P. A., and Thompson, S. B.: J. Bone & Joint Surg. 26: 557–559, July 1944.)

inflammatory condition sometimes masked those caused by fracture of the os calcis.

Roentgenograms (fig. 24) were essential for diagnosis (*33*). Films from all angles were negative within the first 4 or 5 weeks in 51 of the 71 fractures first reported from Camp Wheeler (*14*), and many of these patients returned to duty before the fractures were recognized. When they were readmitted, 5 to 8 weeks after the onset of symptoms, because of recurrence of swelling and pain, it was possible to demonstrate by roentgenograms an irregular, sclerotic line of callus, about a quarter of an inch wide, in the posterior half of the calcaneus, transverse to the long axis and extending incompletely through the bone. The lesion was then clearly recognizable as a healing fracture. In most instances, the condensation line of callus (fig. 25) appeared to run transverse to the heavy lines of stress and trabeculations in the bone (*33*).

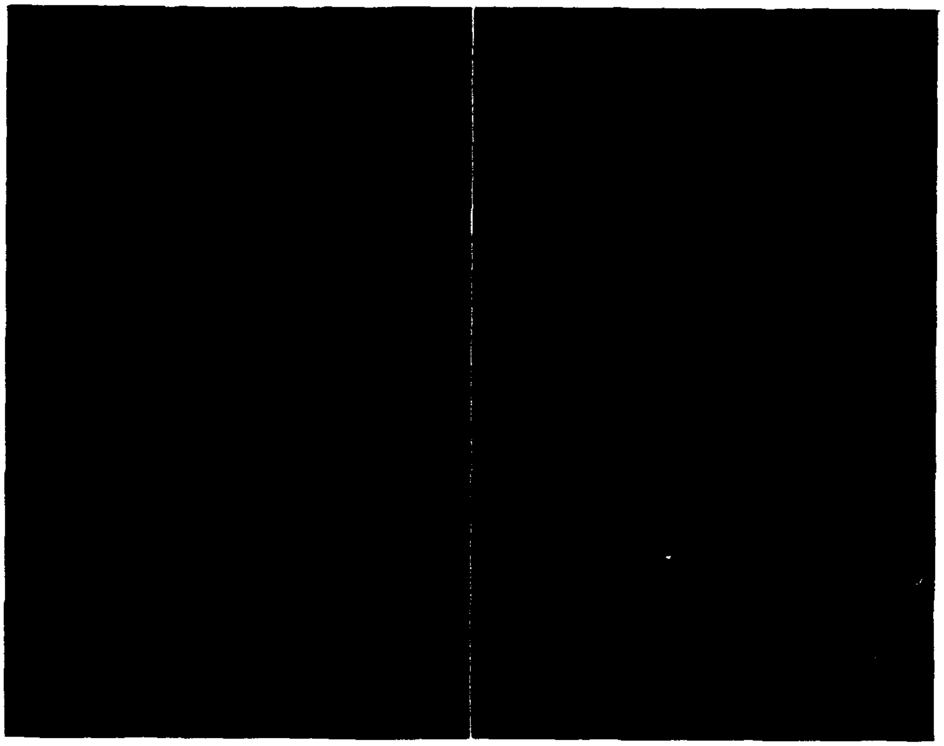


FIGURE 29.—March fracture of distal shaft of right fibula. (Left) Anteroposterior roentgenogram. (Right) Lateral roentgenogram. (Van Demark, R. E., and McCarthy, P. V.: Radiology 46: 496–501, May 1946.)

The pathologic process in march fractures of the os calcis, based on roentgenologic evidence, was described as follows (*14*):

> The process begins as an incomplete fracture of a few of the bony trabeculations within the calcaneus. Because of the anatomic structure of this bone, which is cancellous except for a thin layer of cortical bone, the fracture line extends irregularly in all planes. There is no displacement, and the fracture extends for such a relatively short distance in any single plane that, as already mentioned, X-rays coming from one plane can pass through the fracture line only in that plane, and as a result, the bony separation is not revealed. If trauma is repeated, the fracture line may be extended. A fracture that extends through the cortex originally can, of course, be demonstrated early. Swelling of the overlying tissue and edema occur, as already noted, in all fractures, but there is no ecchymosis, since the bleeding from the fracture site does not penetrate the usually intact cortex and periosteum.

In all but two of the 71 injuries first reported from Camp Wheeler (*14*), the fracture was in the posterior half of the calcaneus. In one instance, there were both anterior and (later) posterior fractures. The left foot was involved in 38 injuries and the right, in 33. Two men had multiple fractures in the same bone; the healing calcifications were evident at different times.

The majority of fractures of the os calcis occurred in older soldiers, of an average age of 30 years, with inadequate muscle development, particu-

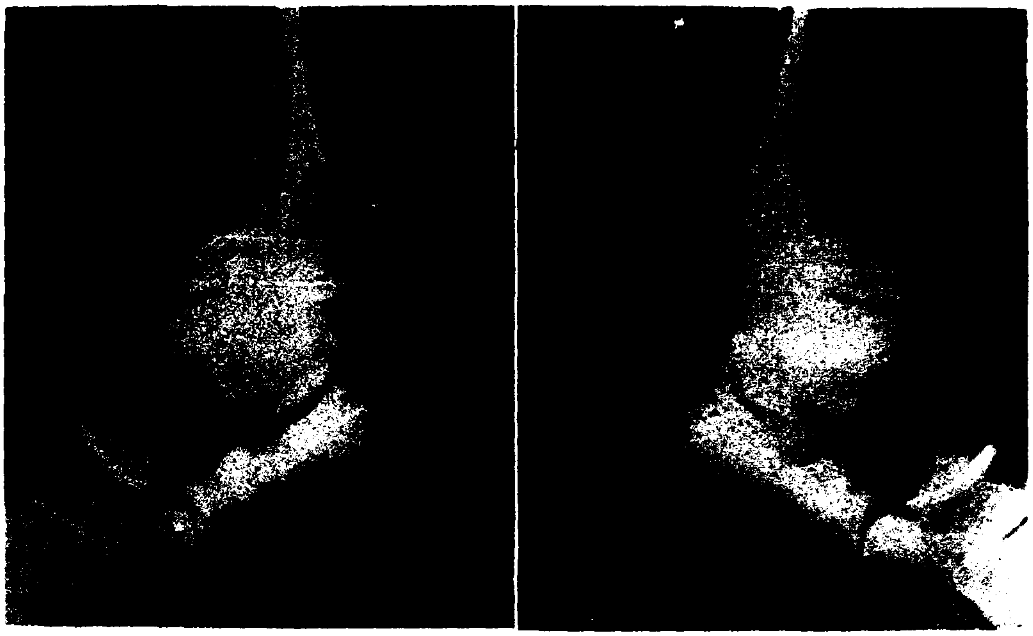


FIGURE 30.—Bilateral march fractures of fibula. The fracture on the right occurred on 28 December 1942, after a 15-mile hike. The fracture on the left occurred about 21 February 1943. This patient later sustained a march fracture of the second right metatarsal bone. (Left) Lateral roentgenogram of right ankle area, 6 January 1943. (Right) Lateral roentgenogram of left ankle area, 4 March 1943. (Hamilton, A. S., and Finklestein, H. E.: J. *Bone & Joint Surg.* 26: 146–147, January 1944.)

larly of the feet and legs. Inadequate personalities were frequent, and many of the patients seemed to have adjusted poorly to the Army training program.

Blood chemistry studies (calcium, phosphorus, phosphatase) in the 10 cases studied were within normal limits.

The correct diagnosis was missed in many of the early cases for two reasons, the negative roentgenograms and the fact that the possible existence of such an injury was not yet realized. The erroneous diagnoses included synovitis of the ankle joint and of the subtalar joint, strain of the subtalar joint, contusion of the heel, and edema of undetermined origin.

Treatment in 70 of the 71 cases consisted of rest, avoidance of weightbearing on the heels, and physical therapy. Later, felt heel inserts or rubber elevations, or both, were used. There were no known recurrences. In the remaining case, in which the fractures were complete and bilateral, molded, unpadded plaster casts were applied for 8 weeks, with good results.

Cuneiform Bones

Fractures of the cuneiform bones are not common. Only one seems to have been reported before the following case was recorded in August 1943 (*7*).

FIGURE 31.—March fracture of distal third of left femur. (Left) Anteroposterior roentgenogram. (Right) Lateral roentgenogram. Note that fracture line is complete, that there is no displacement, and that there is considerable callus formation. (Van Demark, R. E., and McCarthy, P. V.: Radiology 46: 496–501, May 1946.)

Case 2.—A 34-year-old soldier, a plumber in civilian life, had been in the Army for 5 years without previous trouble with his feet when he experienced pain in the right foot after 2 weeks of daily marching and drilling over distances of 5 to 10 miles, while carrying a full pack. The associated midtarsal swelling did not decrease after 4 weeks of hospitalization, on a tentative diagnosis of nonsuppurative cellulitis. Roentgenograms at the end of this period revealed a small amount of calcific debris on the dorsum of the right middle cuneiform bone. The finding was interpreted as either a tumor or a slight infection of the bone. Three weeks later, when the swelling was still present, roentgenograms from various angles revealed a distinct fracture line through the cuneiform bone; and a review of the case, from the onset of symptoms, pointed to the diagnosis of march fracture. Relief was secured by regulated weight-bearing and the use of a medium-soft longitudinal rubber arch support.

Long Bones

Tibia and fibula.—March fractures of the tibia (figs. 26–28), while infrequent, were next in frequency to fractures of the metatarsal bones. There were only four among the 54 march fractures observed over a 12-month period at the regional hospital at Camp Swift, where an average of 30,000 troops were in training at all times (*24*), and only 41 in the 1,157 march fractures observed at Camp Wheeler during the course of the war (*15*). The upper third of the shaft was affected somewhat more frequently than

FIGURE 32.—March fracture of lower third of right femur. These films were made about a month after the onset of symptoms. In the interim, in spite of severe pain, this soldier made a 15-mile hike and went through the infiltration course. (Left) Anteroposterior roentgenogram. (Right) Lateral roentgenogram. (Leveton, A. L.: Am. J. Surg. 71: 222–232, February 1946.)

the lower portion, in which the subperiosteal reaction often did not develop into a complete transverse fracture line (*33*). Some of the fractures in this area were missed under the diagnosis of "shin splints." Some of the reported fractures of the tibia were bilateral, and one of the reported bilateral fractures was multiple on one side (*34*).

Fractures of the fibula (figs. 29 and 30) were even more infrequent than fractures of the tibia. There were only two in the 1,157 march fractures observed at Camp Wheeler (*15*). The distal portion of the shaft was most frequently affected. An occasional injury was bilateral (*35*).

Femur.—A number of march fractures of the femur (figs. 31–36) were observed in the course of the war (*15, 18, 33, 34, 36–39*). The following cases represent various aspects of these injuries in this location:

Case 3.—A 17-year-old soldier, who entered service after many months of inactivity, sustained his injury in a calisthenic drill 8 days later. Roentgenologic examination

FIGURE 33.—March fracture of neck of left femur at base. Although this is an unusual site for such a fracture, there was no doubt of the correctness of the diagnosis. The injury occurred 6 weeks after the soldier had begun infantry training. Healing was uneventful with no treatment other than restricted activity. (Van Demark, R. E., and McCarthy, P. V.: Radiology 46: 496–501, May 1946.)

showed a small crack in the cortex of the femur about 4½ inches above the joint. Since there was no history of trauma, the finding was disregarded. When the patient was reexamined after a week on crutches and 2 weeks of unsupported ambulation, roentgenograms revealed a bony tumefaction in the affected area, and a tentative diagnosis of osteogenic sarcoma was made. Observation over a period of several weeks, with repeated roentgenograms, showed the lesion to be a healing march fracture. Firm bony union was achieved about 4 months after the first examination (*36*).

Case 4.—A 19-year-old recruit, in the eighth week of his basic training, experienced sudden pain in the course of a 12-mile hike with a 40-pound field pack. He continued on duty for 10 days before a diagnosis of march fracture of the femur was made. Healing occurred with a coxa vara deformity (the injury had not been immobilized at any time), but he was able to complete all phases of basic training (*37*).

Case 5.—A 34-year-old soldier developed pain in the hip in the absence of any evident cause. The first roentgenograms were essentially negative except for a slight bilateral alteration of the descending rami of the os pubis. The pain was relieved by several days' rest in bed, but recurred when the patient was returned to duty. A second roentgenogram revealed a transverse fracture of the neck of the left femur. Plaster immobilization was unsuccessful, but good results were eventually achieved with a bone graft (*37*).

FIGURE 34.—Anteroposterior roentgenogram showing march fracture of neck of right femur. In this case, pain in the hip appeared in the first week of basic training. The hip "gave way" 2 days later, while the soldier was going through an obstacle course. The fragments were nailed and traction instituted, but at the end of 7 months, there was no sign of union and a high intertrochanteric osteotomy was performed. (Branch, H. E.: J. Bone & Joint Surg. 26: 387–391, April 1944.)

Other Bones

March fractures have been reported in the ischium (*5*), the pelvis (*39*) (fig. 37), and the pubic bone (*18, 20*). Since the pubis is a flat and relatively thin bone, areas of linear rarefaction and periosteal reaction were plainly evident in it.

Three march fractures of the first rib were observed at one training camp (*40*). This is a location in which fractures of any etiology are extremely uncommon: a search of the literature revealed that only 35 had been reported to date (1945). The three march fractures all occurred in young men, 19 and 20 years of age, while they were carrying barrack bags tied together, slung over their shoulders, and weighing about 40 pounds each. The explanation of the injuries was "microtrauma," "subfractural in intensity," caused by the jogging of the bags as the men march at 100 steps per minute. Since the times at which they were obliged to fall out of

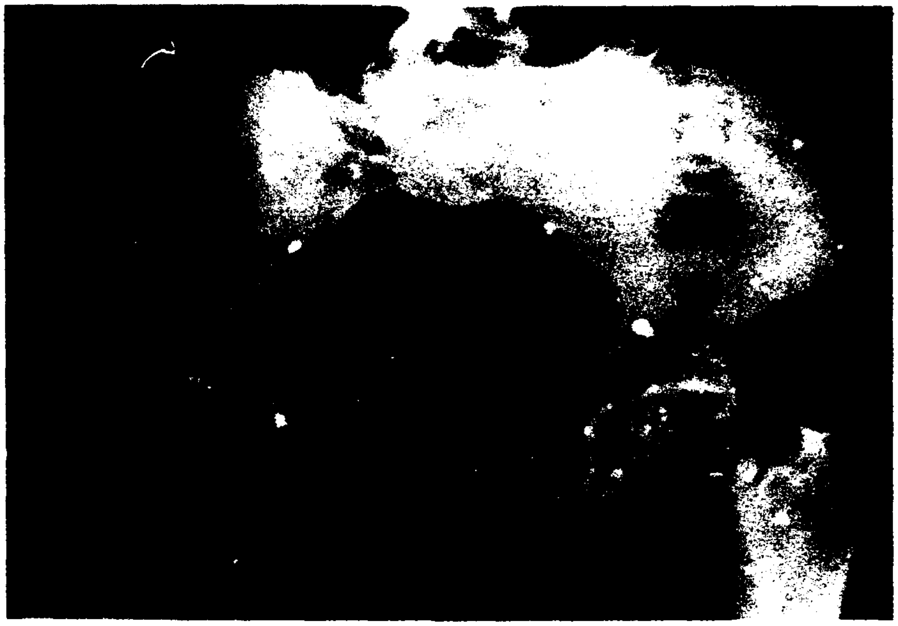


FIGURE 35.—Anteroposterior roentgenogram of pelvis showing march fracture of neck of left femur 3 weeks after injury. Films taken 11 days after injury were reported negative, but when they were reviewed, the fracture was found. The fragments, which are displaced in this view, were in good position in the first set of films. The fracture was reduced and the fragments were fixed with a three-flanged nail, but union did not occur and a high McMurray-type osteotomy was performed. The patient was discharged with a mild limp, but with a stable hip. (Branch, H. E.: J. Bone & Joint Surg. 26: 387–391, April 1944.)

line were known, it was estimated that they had received, respectively, 60, 120, and 180 blows before their injuries occurred. Diagnosis in one case was complicated by the suspicion of cardiac disease; the patient had a history of rheumatic disease in childhood, and the pain pattern suggested coronary angina. The fractures showed up well on routine posteroanterior roentgenograms. Standard anteroposterior projections of the shoulder girdle were less successful. In all three cases, the overlying clavicle prevented visualization of the fracture.

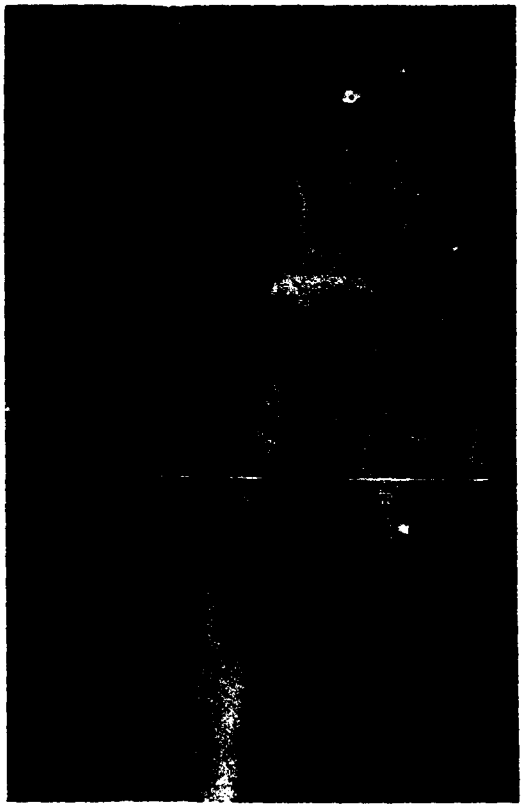


FIGURE 36.—Anteroposterior roentgenogram showing displaced fracture of neck of right femur 3 weeks after hip "gave way." The patient made an uneventful recovery after reduction of the fracture and the application of a double plaster-of-paris spica. (Leveton, A. L.: Am. J. Surg. 71: 222–232, February 1946.)

FIGURE 37.—Anteroposterior roentgenogram showing march fracture of left pelvis through inferior pubic ramus. Note small amount of callus at fracture site. This film was made 6 weeks after the onset of symptoms, when the soldier had completed the 15th week of a 17-week basic training course. (Leveton, A. L.: Am. J. Surg. 71: 222–232, February 1946.)

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CHAPTER V

Orthopedic Injuries in Airborne Troops (Paratroopers) in Training

Roy R. Ciccone, M.D., Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

Combat operations carried out by airborne troops (parachute troops, paratroopers) in World War II promptly proved so successful that the entirely experimental platoons first set up were expanded to supply the urgent demands for larger and far more numerous units. The introduction of this unorthodox type of warfare also introduced new medical problems, the overwhelming majority of which were orthopedic.

HISTORICAL NOTE

Since airborne operations constituted a new branch of warfare and parachute jumping was itself relatively new, the literature on the subject at the beginning of World War II was limited. It was entirely in the foreign (chiefly Russian) journals, and it went back only to 1935. The material was surveyed by Capt. (later Maj.) William J. Tobin, MC, and his associates, and the essential facts were incorporated in one of the early reports from the Group Parachute School, Fort Benning, Ga., as follows (*1*):

> The first published article on parachute injuries, by Gertman of Poland in 1935, dealt with injuries of the ankle and explained their frequency by three physiologic facts:
>
> 1. Although the ankle is the weakest joint in the body, it carries the entire body weight.
> 2. Because the ankle is situated at the terminal periphery of the body, it is exposed to the utmost danger, since the whole length of the body acts on it as the long handle of a lever.
> 3. Because the ankle has no lateral movement, a fracture or sprain is inevitable if the foot is in a fixed position while the body is diverted to one side or the other.

Other earlier writers also commented on the frequency of injuries about the ankle and the lower end of the tibia and fibula. Estrin and Dolbnin (both in 1938) explained these injuries were caused by unequal distribution of body weight. According to Dolbnin, as the parachutist approaches the earth, he often tends to become confused, and in his confusion, he thrusts out one foot or the other to reach for the ground and thus lays that

ankle open to greater chance of injury. Dolbnin also explained the large number of fractures of the posterior lip of the tibia (p. 210) by action of the direct landing force supplemented by a second force; namely, the forward motion of the jumper if he comes in as he should. In these circumstances, the impact of landing is transmitted directly from the metatarsal heads through the long axis of the foot, and the posterior articular surface of the tibia, as a result, is sheared off.

Estrin explained sprains of the external lateral ligaments as due to forced adduction of the foot combined with simultaneous supination. He was opposed to bandaging the ankles prophylactically, believing that more injuries would be incurred by attempted artificial reinforcement of the ligamentous apparatus. Veklenko, Kaptievsky, and Rumshin, however, advocated bandaging the ankles with strips of canvas or using high laced boots. They based their recommendation on observation of 15 parachute fractures, 14 of which were of the lower extremity.

There was general agreement in the earlier literature that injuries were most likely to occur in individuals with little or no experience in sports (Estrin), in poorly selected candidates (Ispahi, Turkey, 1940), and in jumpers with little or no training (Sawicz, Poland, 1938). Sawicz, whose material consisted of 508 jumps, reported an incidence of injuries in trained troops of 1.3 percent, against 10.7 percent in troops with little or no training. Forty-two percent of the injuries in this series were sprains about the ankle.

Goldmann, in 1937, discussed jumping from towers, pointing out that injuries at this stage of training were the result of improper landings. The most common error was the assumption of an asymmetrical position of the feet, so that, during the landing, the center of gravity was displaced and the impact was received on only one foot, which turned, usually inward, with resultant injuries to the ankle and the lower third of the tibia.

Sawicz noted that several days before men were to make their first jumps, the blood pressure, pulse rate, and blood sugar were elevated and respiration was irregular. These manifestations continued until the jumps had been accomplished. This was the period, in his opinion, for the organization medical officer to eliminate men who obviously were emotionally unstable or who were on the borderline of instability.

Sawicz listed the following general causes of parachute injuries, most of them the responsibility of command and not of the jumpers:

1. Allowing novices to jump in unsatisfactory atmospheric conditions and to make jumps from heights below 600 meters.
2. Selection of improper landing grounds, particularly those characterized by ditches, fences, and outhouses.
3. The use of parachutes with diameters too small proportionately for the weights they were called upon to carry.
4. Inadequate attention to the condition of the jumper's skeletal apparatus.
5. Inadequate footgear, especially the use of shoes with high or worndown heels.

6. Improper landing techniques, the result of insufficient training in landing simultaneously on the toes of both feet.

7. Opening of the parachute in such a manner that the suspension lines struck the jumper about his face and neck. This type of injury was another illustration of lack of training in the management of both the body and the parachute in the air.

Goldmann listed a number of reasons for rejection of applicants for parachute training, including poorly reduced old fractures; curvatures of the leg (varus and valgus); habitual dislocations; and flat feet, with complete absence of the arch.

In 1939, in one of the latest of the prewar contributions, deGaulejac (France) classified parachute injuries into:

1. Injuries resulting in death and occurring in the first phase of the jump. They were caused by entanglement with the plane or by failure of the parachute to open.
2. Thoracoabdominal injuries, with or without nerve or vascular complications. They were caused by the shock of the opening of the parachute.
3. Various organic lesions, of diverse localization and origin. They occurred after the parachute had opened.
4. Injuries of the lower extremities, which were more or less complicated and which occurred after contact with the ground.

INCIDENCE OF INJURIES IN WORLD WAR II

The Parachute School at Fort Benning was the major parachute training center for the U.S. Army.[1,2] When hostilities ended, in August 1945, it was graduating approximately 30,000 parachutists per year. The material in this chapter is based primarily on several reports from this school, as follows:

1. In 1941, by Lieutenant Tobin; 1st Lt. (later Maj.) Lawrence J. Cohen, MC; and 1st Lt. (later Maj.) John T. Vandover, MC (*2*).
2. In 1943, by Captain Tobin, with the collaboration of Maj. Roy R. Ciccone, MC, Captain Vandover, and Capt. Charles S. Wohl, MC (*1*). This report has already been cited.
3. In 1943, by Captain Tobin (*3*).
4. In 1944, by Maj. Charles D. Lord, MC, and Lt. Col. (later Col.) James W. Coutts, MC (*4*).
5. In 1945, by Major Ciccone. This (unpublished) report amounted to a summary of orthopedic activities in the Group Parachute School (*5*).

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[1] A parachute injury was defined arbitrarily as a condition which resulted from training and which caused a student to lose a day or more from duty. Minor sprains, lacerations, contusions, or states of exhaustion from which jumpers could be rehabilitated by the Parachute Medical Unit and from which they could be returned to duty in a few hours were not regarded as injuries for statistical purposes. The official statistics cited in this chapter were maintained by the office of the Surgeon of the Parachute School. They do not include postqualification jumps and, therefore, cannot be compared with the report of 20,000 jumps by men of the Sixth Airborne Division (British) made by Essex-Lopresti, which were all postqualification jumps.

[2] The Parachute School, originally the Parachute Section of the Infantry School at Fort Benning, was activated as a separate school on 15 May 1942. It became the Airborne School on 1 January 1946 and reverted to its original status as part of the Infantry School on 1 November 1946.

TABLE 2.—*Casualties in relation to stage of training in 260,401 parachute jumps, Parachute School, Fort Benning, Ga., September 1943–September 1945*

Stage of training	Number of trainees	Injuries			
		Fractures	Soft-tissue	Total	Percent
A	68,359	45	455	500	0.70
B	66,203	48	497	545	.83
C	63,611	95	492	587	.92
D	62,228	354	1,371	1,725	2.74
Total	260,401	542	2,815	3,357	0.76

TABLE 3.—*Casualties in 379,212 plane jumps, Parachute School, Fort Benning, Ga., August 1940–September 1945*

Periods	Number of jumps	Fractures		Other injuries	
		Number	Percent	Number	Percent
1 Aug. 1940–1 Aug. 1941	4,490	25	0.55	121	2.69
1 Aug. 1941–1 Aug. 1942	85,061	247	.29	1,265	1.48
1 Aug. 1942–1 Sept. 1943	(1)	(1)	(1)	(1)	(1)
1 Sept. 1943–1 Sept. 1944	145,816	185	.12	988	.67
1 Sept. 1944–1 Sept. 1945	143,845	169	.11	408	.28
Total	379,212	626		2,782	

[1] Not available.

6. In 1948, by Major Ciccone and Capt. Robert M. Richman, MC (*6*). This article supplemented and expanded Major Ciccone's 1945 report.[8]

Over the total period of operation of the Parachute School at Fort Benning, 137,111 officers and enlisted men underwent training, in the course of which they made a total of 543,561 jumps, in four stages. In the 2-year period ending in September 1945, during which the school was at the peak of its activity, there were 260,401 jumps, with 3,357 injuries, 542 of which were fractures (table 2). These figures, it should be noted, cover all injuries for this period, including the 1,725 injuries in the 62,228 plane jumps made in stage D.

When only plane jumps are considered (for which the breakdown for 1942–43 is unfortunately not available), there were 379,212 jumps with 2,782 injuries, 626 of which were fractures (table 3).

There was, as might have been expected, an increase in the number and rate of injuries as training became more hazardous and plane jumps

[8] Major Ciccone was particularly fitted to write the final reports on these parachute injuries: He had served continuously as Chief of the Orthopedic Section, Army Service Forces Regional Hospital, Fort Benning, from 1941 through 1945, and every injury on the post that required hospitalization was cared for in this hospital.—M. C.

FIGURE 38.—Work on ropes in stage A of parachute training. Right rectus strains, simulating acute appendicitis, sometimes followed unusually strong abdominal efforts at rope-climbing.

were undertaken (table 2). There was also, however, a notable decrease in the overall rate of injuries as time passed, experience was gained, and training techniques were modified. Even these reduced rates were considerably in excess of the rates of injury in other types of military training, but the explanation, of course, is obvious, the greater hazards inherent in paratrooper training.

In the British figures mentioned earlier in the chapter, there were 437 injuries of all types, 2.11 percent, most of them, Essex-Lopresti stated bluntly, being the fault of the jumpers themselves (7). His explanation was that they had become extremely careless after qualification and perhaps had too much confidence in the excellence of their equipment.

SELECTION OF PERSONNEL FOR TRAINING

Candidates for parachute training at the Parachute School at Fort Benning were selected with great care, and by strict criteria (4). Their first examination, by the Unit Medical Officer, served merely as a gross screening process, intended to weed out clearly unfit material. The men who

FIGURE 39.—Judo practice in stage A of parachute training. Landing on bony prominences during this stage was a frequent cause of fractures of the clavicle of acromioclavicular separations.

passed this scrutiny and were admitted to the receiving battalion at the school were then subjected to a rigorous physical and psychologic examination, designed to eliminate men anatomically unfit for this branch of service and to detect any latent lack of desire on the part of the candidates for training of such severity.

The physical examination in the Parachute Medical Unit laid stress on all symptomatic defects, such as old lumbosacral sprains, old fractures that were still painful, and old retracting scars. The examination also delved into any history of symptoms referable to the central nervous system, such as dizziness, blackouts, and fainting spells.

Men with potential or actual hernias, which might become aggravated during training, were not accepted. Applicants with heart murmurs also were ruled out unless the murmurs could positively be proved to be functional. Venereal disease discovered at the original examination disqualified candidates, and those who contracted it during training were immediately eliminated. Syphilitics who had had what was considered adequate treatment and whose blood and spinal fluid serology were negative were accepted. Bilateral vision of 20/40 or better was required.

The process of selection just described resulted in the rejection of 10 to 15 percent of all candidates for parachute training and in the procurement of the best men available from both the physical and the psychologic standpoint. Physically perfect men were less prone to accidents during training, and athletes were particularly adaptable (*1*). An unusually high

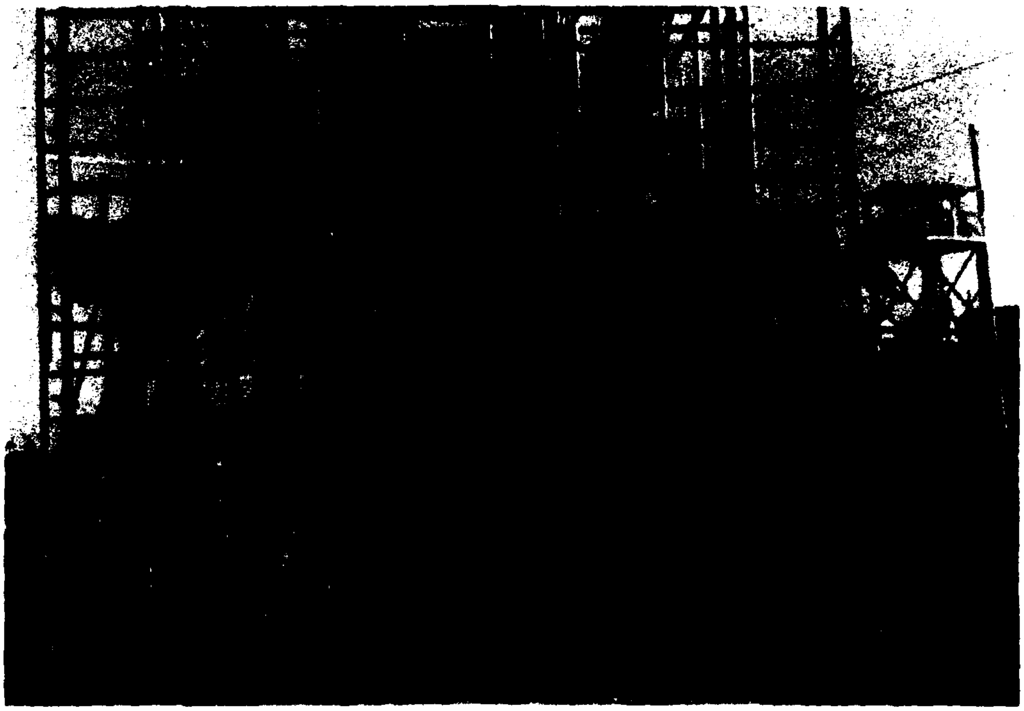

FIGURE 40.—Exercises on the trainasium, the so-called plumber's nightmare. Falls from it caused many injuries, and it was another source of muscular strains of the abdomen. Note the mockup tower in the right background.

incidence of injuries was observed in men over 6 feet tall and in those whose weight averaged more than 155 pounds. The British also observed more casualties among heavier men (7).

Careful observation was practiced all through the training period. If there was any evidence of hesitancy, or actual inability, to perform some of the preliminary low jumping procedures, the man was removed at once from training.

GENERAL CONSIDERATIONS OF PARACHUTE TRAINING

Parachute training at Fort Benning was divided into four stages:

Stage A included calisthenics, rope climbing, running, and jumping from 4- to 6-foot platforms into sawdust bins (figs. 38 and 39). This stage was designed to accomplish physical hardening and to bring the candidates to as near physical perfection as possible. Men who were well trained during this stage were less likely to develop fear phenomena during the next three stages.

Many soft-tissue injuries occurred during this phase of training, in which activities were very strenuous, but since there was little high jumping, bony and ligamentous injuries were not numerous. In the 68,359 jumps

FIGURE 41.—Jumps from landing trainers, simulating parachute landings. Note sawdust bed, to lessen shock of impact. Ankle injuries were caused by the twisting motion that followed landing.

in stage A training during the peak activities of the school (the 2-year period ending on 31 August 1945), there were only 500 injuries, 0.70 percent, only 45 of which were fractures (table 2).

Stage B of parachute training included tumbling, use of the landing trainer, jumps from mock doors (4 to 6 feet) and from mock towers (30 to 35 feet), and suspended harness drill. One of the more ingenious pieces of apparatus used during this stage was the so-called trainasium, appropriately termed the "plumber's nightmare" by the students who were required to swarm over its mass of iron pipes (fig. 40). Jumps from landing trainers simulated actual parachute landings and provided experience in landing without injury (fig. 41). Mock towers (fig. 40) were used for training in exit techniques while conditioning the students to jump from increasingly greater heights. In this phase of training, great emphasis was placed on teaching the student to fall on the padded areas of his body and to avoid the natural tendency to take the shock of the fall on bony prominences (figs. 39 and 42) or on his outstretched hands.

During the period of peak activity at the school, there were 66,203 jumps in stage B training, with 545 injuries, 0.83 percent, 48 of which were fractures (table 2).

Stage C of training included both free and controlled daily jumps from 250-foot towers (fig. 43). In controlled jumps, the student was

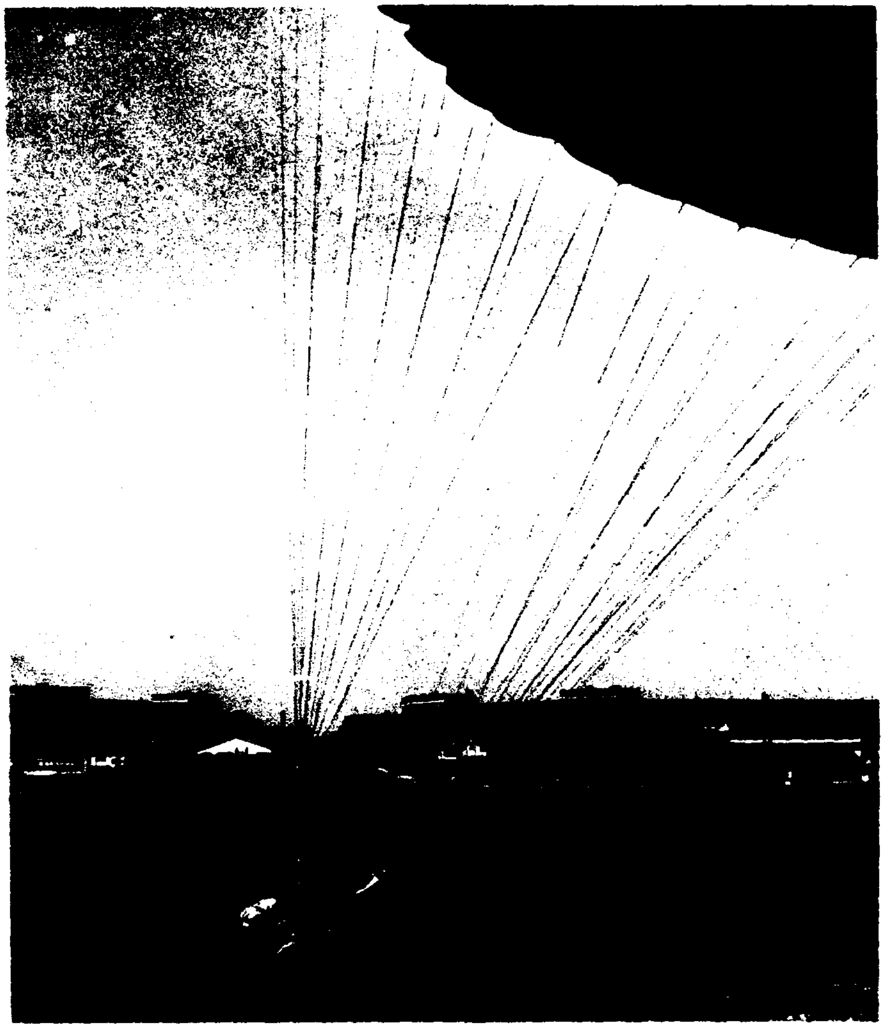

FIGURE 42.—Landing on elbow and shoulder, which was often followed by fractures of the humerus and clavicle or by separation of the acromioclavicular joint.

dropped by parachute, so that he could experience the sensation of an actual parachute descent and could perfect his landing technique. After he had landed, an artificial wind machine dragged him along the ground while he learned to collapse his open chute (fig. 44).

During the period of peak activity at the school, there were 63,611 jumps in stage C training, with 587 injuries, 0.92 percent, 95 of which were fractures (table 2). An analysis by Captain Tobin for the 3-month period ending on 1 August 1942 showed 61 injuries in jumps from the control tower, of which 13 were fractures, and 253 in jumps from the free tower, of which 51 were fractures.

Stage D training consisted of jumping from planes in flight, with landings on both even and uneven terrain. Five such jumps were required

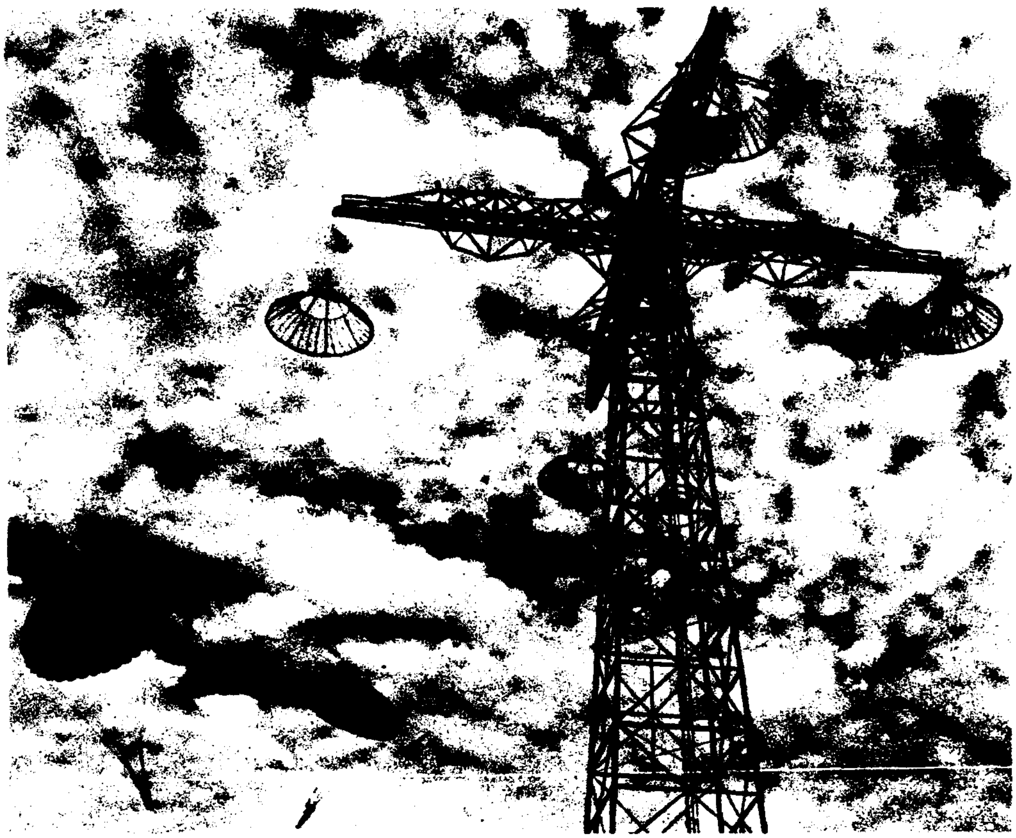

FIGURE 43.—Tower (250-feet high) from which free and controlled jumps were made in stage C of parachute training. Note oscillation set up by ground wind, which could be partly controlled by manipulation of the risers.

for qualification as a parachutist; the British required eight jumps (7). In the early days of the Fort Benning school, when the student load was relatively small, it was possible for the assistant commandant to select the most favorable weather for candidates to make their qualification jumps (4). As the workload increased and the demand for parachutists became more urgent, this consideration was no longer possible and ideal weather conditions could not be selected.

In addition to the trauma of uncontrolled landings in this stage of training, there were other hazards, fortunately not common, such as freakish opening of the parachute (fig. 45), tangling of the parachute in midair, and drop errors on the part of the pilot (fig. 46).

During the period of peak activity at the school, there were 62,228 jumps in stage D training, with 1,725 injuries, 2.77 percent, including 354 fractures. As would be expected, the rate of injury in this stage was several times that of the rate in other stages.

After the soldier was qualified as a parachutist, he was constantly exposed to further hazards in advanced airborne training under conditions

FIGURE 44.—Artificial wind machine used in stage C of parachute training. Failure to collapse the parachute on landing was the cause of many soft-tissue injuries.

that often approximated actual warfare. This type of training was beset with so many physical hazards that it is remarkable that more men were not hurt.

There were 33 deaths in the 543,561 jumps made at Fort Benning, a little under six deaths per 100,000 jumps. None were attributable to orthopedic causes.

LANDING TECHNIQUES

The typical jump in World War II was made from a C–47 plane (the DC–3 commercial transport), which, as it approached the jump zone, slowed down to an air speed of 110 miles per hour.[4] The jumpers stood ready and, at a signal from the jumpmaster, they leapt out of the door, feet first, in rapid succession (figs. 47 and 48). As each man cleared the

[4] Methods of escape from a disabled plane were taught in training to paratroopers and other military personnel, but could not always be followed when the engine was losing power and the controls had been shot away (8). A major hazard was being struck by some detached part of the disabled plane. A blow from the horizontal stabilizer usually meant instant death. If the man survived the blow from it or some other object, frequently he was unconscious and could not open his parachute, though occasionally it was torn open and he parachuted to safety under its power. If the jump had to be made from a low altitude and the chute did not open until just before the man hit the ground, fractures of the foot, ankle, leg (particularly the fibula), and spine were common. In personnel wearing back types of parachutes, dislocation of the shoulder was a common injury as the chute was jerked open. Fractures of the lower thoracic and upper lumbar spinal segments were common because of the jackknifing of the body on landing. Herniation of the nucleus pulposus sometimes followed.

Personnel from disabled planes frequently walked away from the plane both to leave the vicinity and to seek help. If their injuries were about the ankle, this procedure traumatized the synovia and a mild synovitis persisted after healing of the fracture. Permanent grounding was sometimes necessary in such cases.

FIGURE 45.—Unusual landing hazards, which prevent jumpers from assuming the proper landing position and permit an unduly rapid rate of descent. A panel in the parachute on the right has blown out and the damaged parachute is "robbing air" from the adjacent chute. The jumper on the right is entangled in the suspension lines of the other chute and his own reserve chute.

plane, his parachute pack was ripped open automatically by the static line attached to the plane. The canopy unfolded, caught the air, and checked the jumper's downward fall by the so-called opening shock, a violent but—to the parachutist—a reassuring jar. He then floated downwind, controlling his direction and drift to some extent by manipulating the risers overhead.

Jumpers originally were taught to assume an attitude of mild relaxation and to descend with the hips, knees, and ankles slightly flexed (*1*). The feet were in slight to moderate (never marked) equinus and were held shoulder-width apart. The muscles were not tensed, but were alert to absorb the shock of landing at the moment of impact. The jumper was taught to land facing downwind, so that horizontal momentum carried him forward rather than backward. He was taught also to land on his toes, never on his heels, so that the force of landing would be transmitted through the balls of his feet. Once he had touched the ground, he made no attempt to remain standing but twisted to one side and went into a tumble or roll,

FIGURE 46.—Composite drawing, made from slow motion pictures, to illustrate faulty positions assumed as parachutists rush out of door of plane. The man third from the plane has spun around too far and will sustain a violent jerk when his chute opens. The man fifth from the plane has caught his left leg in the suspension lines and is likely to sustain a rupture of the ligaments of the knee.

onto the muscular areas of the calf, thigh, buttocks, and back. Then he threw off his harness and was ready for action.[5]

The untrained jumper was likely to freeze as he approached the ground. If he landed stiff-legged, he suffered a fractured heel (heels); if he lunged forward on his outstretched hands, he paid for the error with fractured wrists. The trained parachutist had been taught to avoid these risks. All phases of the actual jump, from opening shock to landing impact, were simulated by special apparatus before live jumps were made, so that ultimately a smooth followthrough from the jump to the cushioned landing fall was automatic.

As experience with jumping increased, it was found that to land with the feet apart apparently increased the chances of landing on one foot and

[5] The British estimated that all but 0.5 percent of injured paratroopers were able to carry on fighting (7). Similar figures are not available for the school at Fort Benning.

FIGURE 47.—Field paratroopers waiting call to make their first jumps at the Fort William Henry Harrison training center of the joint U.S.-Canadian First Special Service Force, 1943. Jumpmaster is kneeling at extreme lower right.

that it was much safer to land with the feet together, so as to divide the shock evenly on both sides of the body. The legs were slightly bent at the knees, and the weight of the body was slightly forward over the feet (fig. 49). Further emphasis was put upon keeping the feet together as the man jumped from the plane, to avoid injuries that might occur if his legs became entangled in the suspension lines of the opening parachute (fig. 46). This new method of landing was inaugurated on 12 June 1943, and the immediate decrease in the weekly incidence of injuries left no doubt of the cause-and-effect relation.

A great deal of attention was also devoted to the original technique of tumbling: improper execution of the maneuver caused a large number of injuries, particularly acromioclavicular injuries (figs. 39, 50, and 51). The theory of tumbling was that the jumper would automatically follow his landing with a smoothly executed tumble, during which the tip of the shoulder did not touch the ground, and the forearm, held rigid by the triceps, acted as a bar over which the body would roll. Correct tumbling was a skill acquired only with prolonged practice, and some individuals with poor agility never acquired it.

When tumbling was abandoned in favor of the cushioned fall, there was an immediate decrease in shoulder injuries. There was also an im-

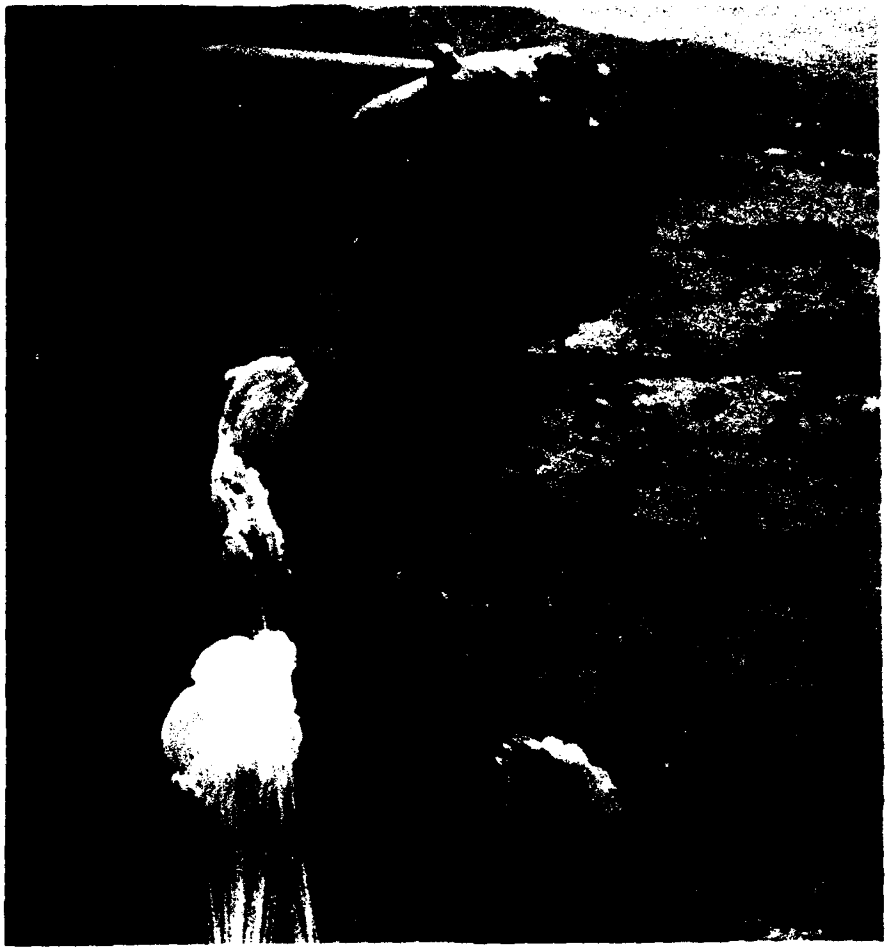

FIGURE 48.—Paratroopers leaving C-47 plane over Camp Cable, Queensland, Australia, in their first practice jump in the Southwest Pacific Area, May 1944.

provement when the tumbling technique was so modified that a proper landing could be made in ground approaches angular to the line of drift during descent.

In addition to adequate training in correct techniques of landing, other considerations prevented injuries during jumps. Uniforms had to be fitted accurately, being neither too tight nor too loose. Footgear must fit properly. Boots must be flexible but, at the same time, give good support to the ankles. When Major Ciccone initiated an investigation of shoes and socks at the Parachute School at Fort Benning, he found many students wearing socks that were too short. This error was readily corrected. He also found that the double straps of the boots then worn did not remain in the slots intended for them and not infrequently tangled in the shroud of the parachute, with resulting typical injuries of the ankle, the head of the fibula, and sometimes the knee joint. The design of the boots was promptly changed.

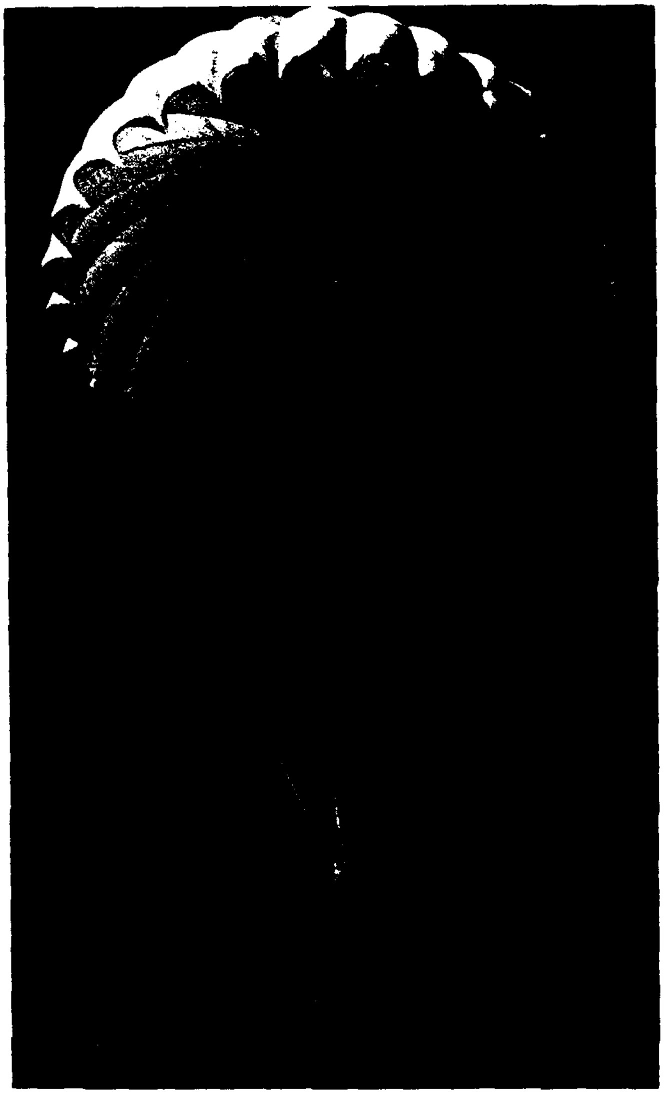

FIGURE 49.—Jumper in proper position for landing. The hips, knees, and ankles are moderately flexed, and the feet are together, in accordance with the revised technique. He is using his arms to pull himself up in preparation for contact with the ground.

MECHANISM OF INJURY

The experience at Fort Benning, confirmed by a review of the histories of the thousands of parachutists trained there, showed that the anatomic distribution of parachute fractures differed in certain important respects from fractures encountered in more conventional military surgery. Parachute injuries showed a definite, almost overwhelming predilection for the weight-bearing structures of the body. In the 2,709 parachute fractures

FIGURE 50.—Forward tumble, originally used but later abandoned in favor of cushioned fall because of numerous shoulder injuries when bony prominences of the body struck the ground.

analyzed in the final report from Fort Benning (table 4), 2,331 were of the lower extremity and 1,462 of this number were of the ankle (*6*). In sharp contrast, there were only 156 fractures of the upper extremity. Fractures of the posterior tibial margin (p. 176) and of the metatarsals were frequent. Fractures of the calcaneus and of the neck of the femur were infrequent. Fractures of the wrist and the hand, so commonly associated with falls in civilian life, were seldom observed in parachutists because of the careful training already described.

Soft-tissue injuries were also more frequent in the lower than in the upper extremity (table 5), though the predominance was less marked than in fractures.

A correctly executed jump and landing were associated with very little trauma. The injuries which did occur could be attributed to specific traumatic mechanisms, which tended to be recurrent and which, as just pointed out, were operative by preference in certain portions of the body. These mechanisms were (1) torsion plus landing thrust, (2) backward landing, (3) opening shock, and (4) violent vertical fall.

Torsion plus landing thrust.—The first of these mechanisms, torsion plus landing thrust, was the most frequent and accounted for 80 percent or more of all injuries. As Major Ciccone and Captain Richman explained it,

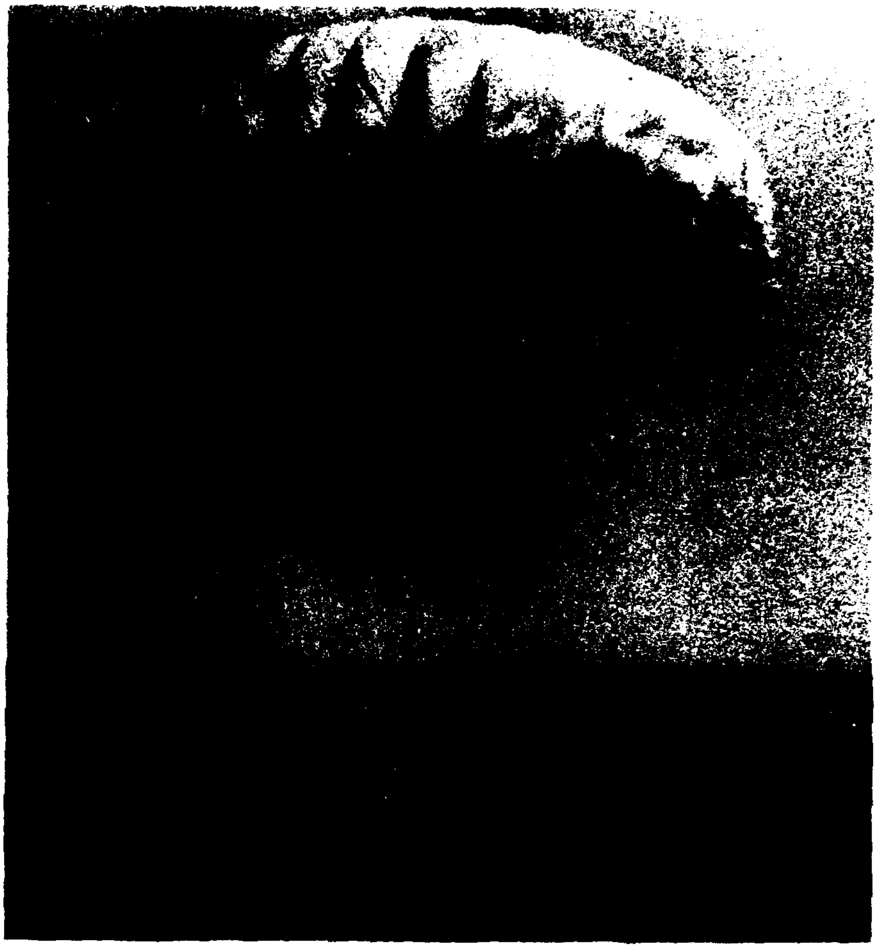

FIGURE 51.—Jumper in middle of tumble stage of landing, in which injuries to shoulder, spine, and skull were likely to occur.

this mechanism represents simply an exaggeration of the forces normally encountered in a parachute landing. As the parachutist descends with a downward and forward momentum, gravity and wind drift contribute, respectively, the main vertical and horizontal components. As he strikes the ground, an upward and backward reactive thrust (termed "landing thrust") is generated against his feet (fig. 52). Also, he experiences various torsional stresses, some due to uneven terrain and some due to oscillation caused by ground wind. Ground wind is an exceedingly traumatizing factor. It not only increases the rate of drift; it also sets up an oscillatory [6] motion that makes the parachutist swing back and forth beneath the canopy of his parachute like a pendulum (fig. 53). Under normal conditions, these stresses are not violent enough to cause injury; the impact is transmitted through the foot and ankle and is dissipated against the elastic resistance

[6] Attempts during the war to develop a nonoscillating type of parachute were all unsuccessful.

TABLE 4.—*Anatomic distribution of 2,709 fractures sustained in parachute training, Airborne School, Fort Benning, Ga.*

Location	Number			Percent
Lower extremity			2,331	86.0
Ankle		1,462		
External malleolus alone	635			
Posterior tibial margin alone	319			
External malleolus plus posterior tibial margin	218			
Bimalleolar fracture with fracture of posterior margin of tibia	112			
Internal malleolus alone	99			
Bimalleolar	60			
Others	19			
Metatarsals		385		
Single metatarsal	90			
Multiple metatarsals	103			
Tarsals		186		
Talus	54			
Navicular	49			
Calcaneus	40			
Cuboid	27			
Cuneiform bones	4			
Phalanges	12			
Tibia and fibula (shafts)		251		
Tibia plus fibula	125			
Tibia alone	27			
Fibula alone	78			
Tibial plateau (including tibial spines)	21			
Femur		36		
Patella		11		
Trunk			206	7.6
Vertebrae (total)		168		
Single vertebrae	80			
Multiple vertebrae	41			
Pelvis		22		
Transverse processes of vertebrae		8		
Ribs		8		
Upper extremity			156	5.8
Humerus		38		
Shaft	16			
Greater tuberosity	22			
Clavicle		35		
Scapula		6		
Olecranon		5		
Radius		26		
Head	11			
Shaft	5			
Colles' fracture	10			
Carpals and metacarpals		26		
Phalanges		20		
Others			16	.6
Total			2,709	100.0

Source: Ciccone, R., and Richman, R. M.: The Mechanism of Injury and the Distribution of Three Thousand Fractures and Dislocations Caused by Parachute Jumping. J. Bone & Joint Surg. 30A: 77–97, January 1948.

TABLE 5.—*Distribution of 196 major soft-tissue injuries*[1] *sustained in parachute training, Airborne School, Fort Benning, Ga.*

Injuries	Number	
	Subtotal	Total
Tears of ligaments of knee	....	93
Abduction instability	88	
Adduction instability	4	
Complete dislocation (anterior)	1	
Dislocations of shoulder	....	39
Acromioclavicular separations	....	23
Dislocations of elbow	....	9
Dislocations of head of fibula	....	8
Separations of symphysis pubis	....	8
Metatarsophalangeal dislocations	....	8
Metacarpophalangeal dislocations	....	3
Carpometacarpal dislocations	....	2
Tears of biceps muscle	....	2
Dislocations of hip	....	1
Total	....	196

[1] Exclusive of 110 cerebral concussions.

Source: Ciccone, R., and Richman, R. M.: The Mechanism of Injury and the Distribution of Three Thousand Fractures and Dislocations Caused by Parachute Jumping. J. Bone & Joint Surg. 30A: 77–97, January 1948.

of the muscles and supporting structures. When, however, these landing stresses are exaggerated by unfavorable jumping conditions, the landing may be both violent and unpredictable. All sorts of directions of drift and oscillation may complicate the picture and may exceed the—still unknown—physical tolerance of the body, disrupt the supporting structures, and produce a wide variety of fractures, sprains, and dislocations (fig. 54).

A typical parachute landing might be compared to jumping off the top of a moving train; the height of the vehicle contributes to the downward impact and the speed corresponds to the wind drift.

The drift of the parachute, however, was only occasionally in a true forward direction. More often, it was oblique, and its direction thus imparted an external rotatory force to the feet. In addition, the downward and forward motion of the body was arrested as the toes struck the ground, and an upward and backward thrust was thus transferred against the foot and ankle and continued up the leg (fig. 55).

External torsion injuries far outnumbered those caused by internal torsion, probably because the supporting structures are more rigid, and therefore more vulnerable, under stress of external rotation. Combined with various degrees of landing thrust, external rotation could be responsible for a chain of injuries extending from the toes to the hip. These injuries differed widely in pattern as well as location, but they were all related by

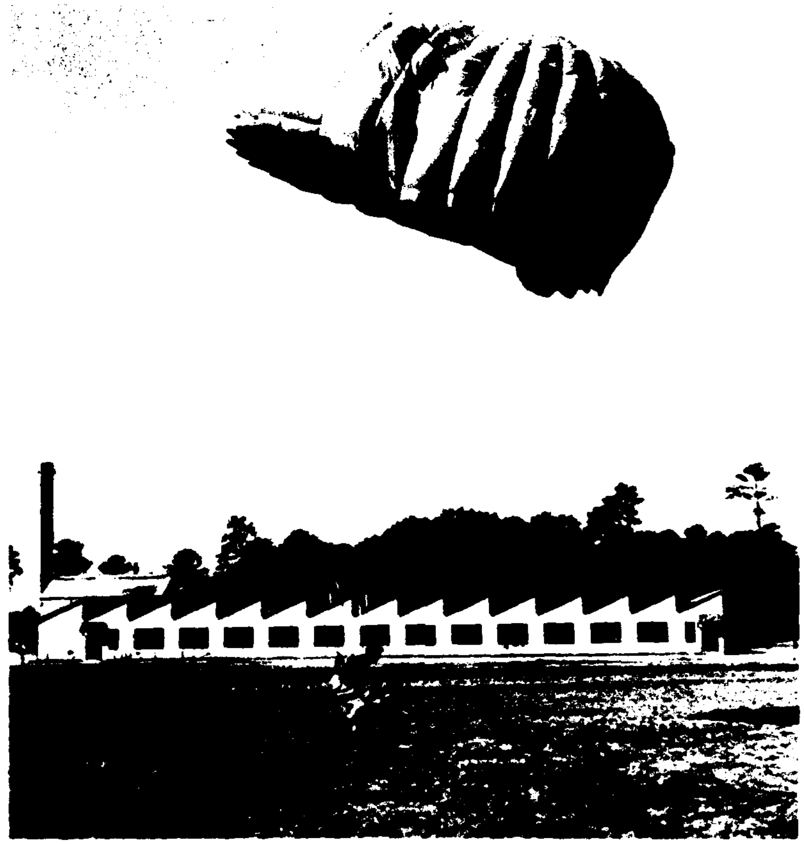

FIGURE 52.—Forceful upward and backward thrust expended on feet as jumper makes contact with ground.

the same common denominator and the same etiologic mechanism (*6*). They included:

Foot. Dorsal dislocation of the toes, multiple or single metatarsal fractures, compression fractures of the mid tarsal bones.

Ankle. Oblique fracture of the lateral malleolus, vertical fracture of posterior tibial margin, combined fractures of lateral malleolus and posterior tibial margin, diastasis of tibiofibular syndesmosis, bimalleolar fracture with or without fracture of the posterior margin of the tibia at the ankle, solitary fracture of the internal malleolus, various combinations of malleolar and leg fractures.

Leg and knee. Spiral fracture of the shaft of the tibia; oblique fracture of the shaft or neck of the fibula, combined spiral fractures of the tibia and fibula, dislocation of the head of the fibula, tear of the medial meniscus of the knee, tear of the medial collateral ligament of the knee.

Thigh. Spiral fracture of the shaft of the femur, fracture of the neck of the femur.

Medical officers at Fort Benning emphasized that all combinations of the injuries were possible, since trauma does not respect arbitrary anatomic boundaries. Parachute injuries, in fact, are an excellent illustration of the fallacy of trying to classify lesions by location rather than by underlying

FIGURE 53.—Oscillation of parachutist caused by ground wind. When oscillation occurs so close to the ground, the jumper has little time or opportunity to correct it by allowing some of the air to spill out of the chute.

mechanism. An analysis of the last 300 injuries of the ankle observed at Fort Benning in the Parachute School was made on this basis (table 6) and correlated well with clinical, roentgenologic, and surgical findings (*6*). It was pointed out, however, that the evidence in all these injuries was largely circumstantial and that it would be a mistake to strain it too far by postulating a theoretical sequence of trauma or by intricate subclassifications and tortured analogies with the laws of mechanics. The important point is the preponderance of external rotation injuries, which is duplicated in other reported series. The analysis showed that the vulnerability of the ankle to external rotation represents an inherent weakness of the joint—

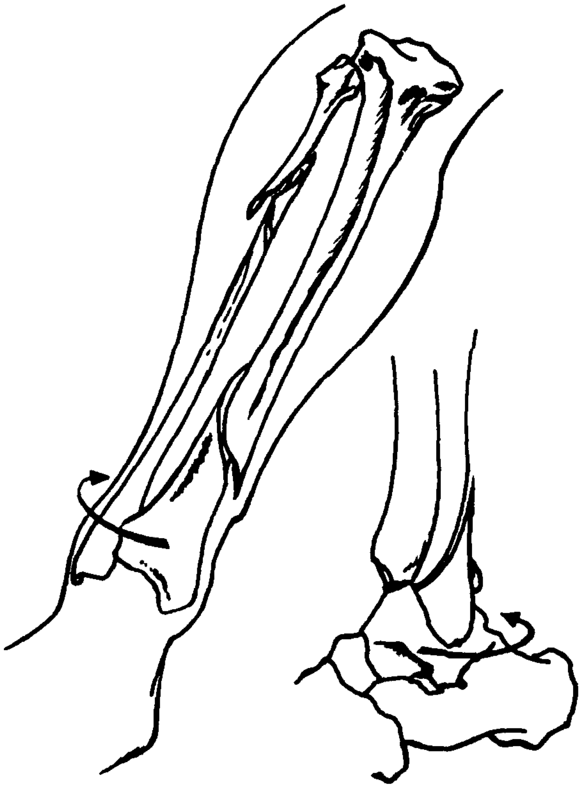

FIGURE 54.—Mechanism of external torsion fractures, with examples of two classical types. (Left) Spiral oblique fracture of distal third of tibia and T-fracture of proximal third of fibula. (Right) Oblique fracture of lateral malleolus.

either a local structural weakness or a lack of adaptive resiliency of the leg as a whole. The Fort Benning experience suggested that the latter of these theories was correct because not only the ankle but the entire lower extremity showed a statistical preponderance of external rotation injuries.

Backward landings.—In backward landings, the second cause of injury among parachutists, the hazard again was oscillation. The jumper struck the ground at the peak of a pendulum-like swing. With his feet swept out from under him, he had no opportunity to roll or cushion his landing, and he fell abruptly backward onto his buttocks and head (figs. 56 and 57). When he landed in the classical jackknife position, the resulting compression force produced numerous vertebral fractures, almost a third of which were multiple and most of which occurred at the dorsolumbar junction and the level of the sixth dorsal vertebra. The cancellous bone of the vertebrae was crushed anteriorly by the violent hyperflexion of the spine, and the superior surface of the vertebral body almost invariably was compressed downward toward the inferior surface. Multiple fractures did not always occur in

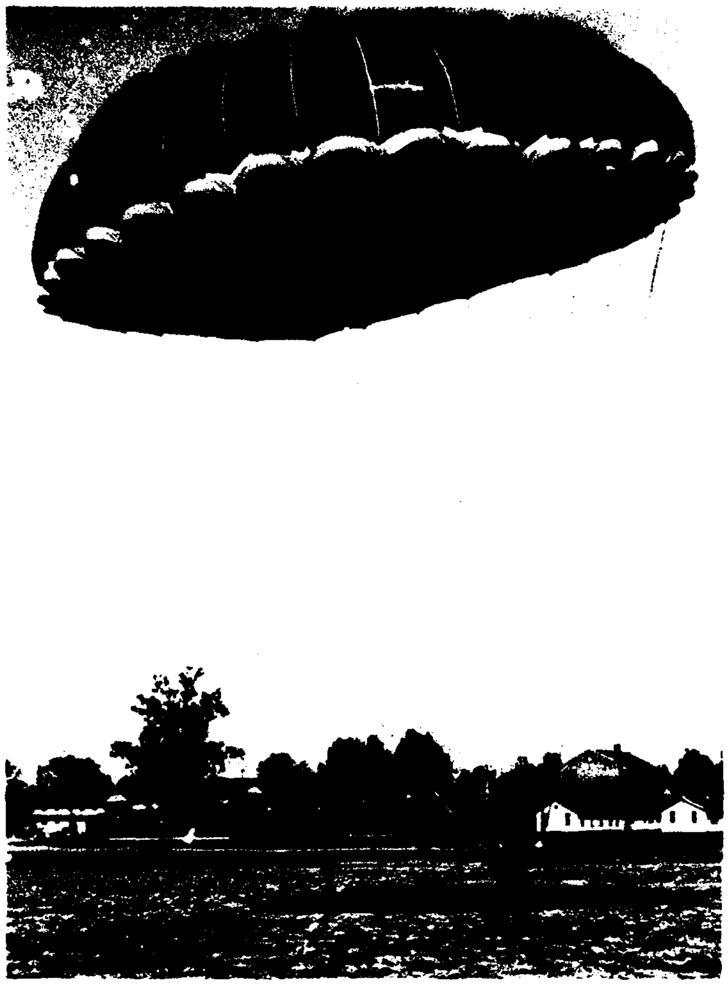

FIGURE 55.—Demonstration of impact that is most frequent cause of injury to lower leg. The external rotatory force is evident bilaterally and successively involves the foot, the ankle, and the leg. The upward and backward thrust is provided by the forward position assumed by the jumper.

adjacent vertebrae. Paraplegia and dislocations fortunately were uncommon in the Parachute School experience.

Associated soft-tissue injuries were almost as potent a source of disability in backward landings as the vertebral fractures themselves; they included low back sprains, herniated intervertebral discs, contusions of the coccyx, and traumatic myositis. The true incidence of these injuries is not known, parachutists being inclined to make light of minor injuries unless they were practically disabled. It was estimated that there were probably 10 soft-tissue injuries of the spine for every compression fracture. Most of them appeared trivial at first, but sequelae were notoriously troublesome, and many men were ultimately disqualified from further parachute duty.

TABLE 6.—*Mechanism of injury in 300 fractures of the ankle sustained in parachute training, Airborne School, Fort Benning, Ga.*

Mechanism	Number of fractures	
	Subtotals	Totals
External rotation (including abduction)	....	157
Oblique fracture of lower end of fibula	128	
Oblique fracture of fibula plus fracture of anterior tibial tubercle	2	
Medial malleolus	13	
Fracture of medial malleolus plus oblique fracture of fibula	13	
Fracture of medial malleolus plus comminuted fracture of fibula (abduction)	1	
External rotation plus landing thrust	....	83
Oblique fracture of fibula plus fracture of posterior tibial margin	55	
Fracture of medial malleolus plus fracture of posterior tibial margin	2	
Bimalleolar fracture plus fracture of posterior tibial margin	25	
Spiral fracture of shafts of tibia and fibula plus fracture of posterior tibial margin	1	
Landing thrust	....	47
Solitary fracture of posterior tibial margin	47	
Adduction	....	8
Transverse fracture of lateral malleolus (excluding chip fractures)	3	
Bimalleolar fracture	4	
Fracture of medial malleolus	1	
Vertical compression	....	2
Extensive comminution of lower ends of tibia and fibula	2	
Undetermined mechanism	....	3
Total	....	300

Source: Ciccone, R., and Richman, R. M.: The Mechanism of Injury and the Distribution of Three Thousand Fractures and Dislocations Caused by Parachute Jumping. J. Bone & Joint Surg. 30A: 77–97, January 1948.

In this group of backward landings at Fort Benning were 110 injuries of the head, ranging from momentarily dazed confusion to cerebral lacerations and fatal intracranial hemorrhage. These injuries were not of orthopedic concern.

Opening shock.—Opening shock, which is a hazard peculiar to parachute jumping, may be defined as the force, of considerable violence, that arises when the parachute snaps open and checks the forward speed of the jumper (fig. 58), usually 100 to 110 miles per hour. The risk of injury depends upon the position of the parachutist's body at the moment the parachute opens. If he has jumped from the plane correctly, the shock is well distributed by the harness and is absorbed with little discomfort. If

FIGURE 56.—Backward landing. As parachutist's feet are swept from under him, he lands directly on his buttocks and the entire impact of the landing is transmitted to the spine.

he dives, somersaults, or spins into a vulnerable body position, the violent jerk of the parachute can be highly damaging.

These injuries are of two types:

1. In whiplash injuries, the jumper is out of line with the tug of the opening parachute and is likely to be flipped upsidedown. Injuries include sprains of the neck, transient neuropathies of the brachial plexus, and ecchymotic brush burns, usually minor, over the clavicles from the slap of the risers.

2. Suspension line injuries are more frequent. The arms or legs may become entangled in the lines while the parachute is unfurling from its pack (fig. 46). If the jumper cannot disentangle himself immediately, the slack lines may suddenly pull taut and wrench the extremity with great violence, rupturing ligaments, muscles, and even bones. In this series, over half of the fractures of the humerus, more than a third of the fractures of the femur, and a large number of the tears of the medial collateral and cruciate ligaments of the knee were caused in midair by this bizarre mechanism. Other serious injuries from the same cause included dislocation of the shoulder, diastasis of the symphysis pubis, tears of the biceps and coracobrachialis muscles, and, in one instance, amputation of a finger when a suspension line caught in a jumper's ring.

Two unusual cases warrant record:

Case 1.—This parachutist, as later investigation showed, dived rather than jumped from the plane and failed to keep his feet and legs together as he made his exit. He

FIGURE 57.—Backward landing with forceful squat that may result in injury to pelvis and spine.

then performed a forward somersault, with his legs still apart, before his chute opened. The suspension line went between his legs, and when it became taut, it exerted so much force on the perineal area as to cause a laceration that extended from the scrotum into the sphincter and that was deep enough to expose the lower segment of the rectum. This was a highly instructive case, showing, as it did, the consequences of failing to follow regulations in every respect.

Case 2.—This parachutist jumped in the prescribed manner from a plane going about 120 miles per hour, but in some way, his parachute opened prematurely and became hooked onto the tail of the plane. The jumper was spun around at a terrific rate of speed for about 10 minutes, but just before he lost consciousness he pulled his reserve chute open, and the opening shock pulled him away from the plane, saving his life but violently dislocating his left hip.

Violent vertical landings.—The U.S. parachute assembly used in World War II provided for a normal drop of 20 feet per second, subject to variations caused by the weight of the parachutist and his equipment. If ground wind and oscillation were minimal, the landing was equivalent to that of a 7-foot drop.

The situation, of course, was not always normal. The rate of fall was sometimes accelerated dangerously. The suspension lines might become entangled or fouled across the parachute. A panel of the silk parachute might be ripped off by the force of the opening shock. The jumpers might drift

FIGURE 58.—Parachutes opening as jumpers leave plane. The third parachute from the plane has not opened properly at this time. When it does open, the jumper may have his leg violently abducted by the suspension lines between his legs.

too close together and, like sailboats, spill the air from each other's parachute. Whatever the mechanism, the ultimate effect was the same: The normal parachute support was reduced, and the landing impact was exaggerated far beyond the structural resistance of the body. Extremely severe and often spectacular injuries could result, including multiple injuries, but compound fractures were not usual.

GENERAL PRINCIPLES OF MANAGEMENT OF INJURIES

Two ambulances and two medical officers were always present when jumps were to be made, and injured parachutists in the A, B, and C stages of training were seen within minutes of their injuries, so promptly, in fact, that in many instances, fractures could be palpated because there was no edema to obscure the field.

Injuries in the D stage of training were handled somewhat differently. An aidman on the jumping field followed the descent of the parachutist assigned to him and was within 6 feet of him when he landed. If there was any evidence whatsoever of injury, the aidman unfolded a red flag, and an ambulance with a medical officer was on the scene within 2 minutes, on the average, from the time of the landing.

Jumpers with fractures, evident or suspected, at any stage of training were transported at once to the Parachute Medical Unit, where roentgeno-

grams were taken. Those with fractures were admitted to the unit. Those with sprains, contusions, and similar injuries were supplied with crutches after initial treatment and were encouraged to be ambulatory.

The management of parachute injuries was, in general, by the principles and practices that would be used for similar injuries in civilian life. A few (of the few) compound fractures were handled by debridement and delayed primary wound closure, as an added factor of safety. Particular attention was paid to accurate reduction of all fractures, though fluoroscopy was not used. Occasional fractures involving the joint surfaces and other fractures prone to slip after reduction were handled by open reduction. Suspension traction was used in fractures of the long bones. Weight-bearing with braces or casts was introduced as soon as possible, to stimulate healing.

The treatment of sprains for the first 24 hours was icing, tight bandaging, and immobilization. A supply of ice was maintained in the treatment area on the field after it was found that icing materially reduced swelling. Thereafter, treatment consisted of warm applications, gentle massage, and early active motion. On two occasions, the Parachute Medical Unit conducted studies to determine the value of injection of sprains with Novocain (procaine hydrochloride). This method was found to be very useful in selected patients whose pain was severe or who, for one reason or another, had to walk immediately. Pain was seldom a problem, however, with the routine described. Novocain injections did not shorten the period of disability, probably because practically complete healing was required before jumpers could return to jump status. Casualties were kept off duty until complete recovery, but even then they showed a tendency, entirely unconscious, to protect the injured member. One jumper with a fracture of the external malleolus was allowed to return to full duty too soon, and on his first jump he sustained a similar contralateral fracture.

No definite scale of disability was formulated, but the policy, because there were no precedents, was in general highly conservative. The ordinary ankle sprain meant about 2 weeks' loss of duty, longer if the sprain was severe. Men with simple external malleolar fractures were not allowed to return to jump status under 4 months. Those with bimalleolar and trimalleolar fractures, with fractures into major weight-bearing joints, and with fractures of the spine usually were transferred to permanent non-jump status.

The Parachute Medical Unit had a well-equipped and well-staffed physical therapy department, which was employed promptly in all injuries. It treated hundreds of men daily with infrared and ultraviolet therapy, whirlpool baths, alternating hot and cold baths, and massage. The rehabilitation program was tremendously advanced when the formal Army reconditioning program was instituted, since the latter picked up the slack inevitable during the long convalescence required by most orthopedic injuries.

SOFT-TISSUE INJURIES

Soft-tissue parachute injuries far outnumbered fractures, but were of far less clinical significance. The majority of jumpers who sustained them did not require hospitalization and seldom suffered any prolonged disability. The final figures for Fort Benning (table 5) showed only 196 recorded soft-tissue injuries, exclusive of cerebral concussions, the small number sustaining the impression that most of them were never reported.

A sprain or tear of the right rectus muscle was the most frequent type of soft-tissue injury sustained during the A stage of training, and the most interesting clinically because it so closely simulated acute appendicitis that many men were hospitalized for observation, and one patient was operated on; when a hematoma was found just below the rectus muscle, the wound was closed without further exploration.

This injury occurred in rope climbing (fig. 38), presumably when the lower extremities were raised at right angles to the body and the legs grasped the rope. When an attempt was made to reach the top of the rope from this position, an unusually strong effort was sometimes followed by a sharp pain in the abdomen. In 90 percent of the cases, the pain was on the right side, probably because the greater effort was usually on that side.

When the typical patient appeared at the Parachute Medical Unit, he walked with his hips slightly flexed because of abdominal pain, which was increased merely by his getting onto the examining table. The rectus muscle was exquisitely tender on light palpation, and deep pressure of any degree was resisted. Severe pain was experienced when an attempt was made to raise the body from the prone position while keeping the lower extremities flat on the table. In the erect position, the abdomen appeared relaxed, but if a hematoma was present, a definite bulge was evident along the course of the rectus muscle. Subcutaneous ecchymosis, extending downward from the point of maximum tenderness, appeared from 4 to 7 days after injury.

White blood cell counts the day after injury might be between 9,000 and 11,000 per cubic millimeter, with polymorphonuclear leukocytes from 70 to 80 percent, both findings being additionally suggestive of acute appendicitis.

Once the possibility of this injury had been realized, diagnosis presented no further difficulties. Clinical improvement was gradual.

REGIONAL INJURIES

The basic mechanism of most regional parachute injuries has already been presented, but, at the risk of some repetition, it might be useful to record certain additional facts.

Shoulder.—The most common type of fracture about the shoulder was caused by the opening of the parachute, the force from which was exerted on the clavicle.

When tumbling was not correctly executed, usually in the A and B stages of training, the shoulder came into direct contact with the ground, and the result could be a typical acromioclavicular contusion and separation (figs. 39, 40, 42, and 50). In injuries that were not severe, the joint separation involved only tearing of the articular capsule. The coracoclavicular ligaments remained intact and prevented downward displacement of the scapula and the acromion process. In more severe injuries, the capsule and the coracoclavicular ligaments were torn, and the acromion, being completely separated from the clavicle, was displaced downward by the weight of the upper extremity. In some instances in which the separation was marked, the scapula and acromion were only slightly depressed.

Mild acromioclavicular separations, with slight if any tearing of the capsule, responded well to immobilization of the upper arm and shoulder for 2 to 4 weeks. These students frequently were ready for full parachute duty after this period, with no additional treatment except rest and physiotherapy.

In one instance in which it was thought that the coracoclavicular ligaments had been stretched but had not lost their connection with the clavicle, the patient was treated by a block placed in the axilla and strapped to the body; another strap, extending up over the end of the clavicle and shoulder and down posteriorly, was attached to the block behind the axilla. A sling kept the elbow raised. This patient returned to full training after 5 months, was qualified as a parachutist, and had no residual symptoms referable to the shoulder.

Upper extremity.—Fractures of the upper extremity, as already mentioned, were not frequent (table 4), though on the analogy of civilian experience, Colles' and other fractures might have been expected to comprise a large group. The explanation for their infrequency was that the jumper used his arms to manipulate the risers of his parachute and, as already mentioned, was carefully trained to keep them off the ground during landings.

Fractures of the surgical neck and the tuberosity of the humerus were chiefly due to contact between the shoulder and the ground, as in tumbling, or to direct force on the shoulder as in jujitsu practice (fig. 39). One jumper sustained a comminuted fracture of the shaft of the humerus when his arm became entangled in the shroudlines of the parachute. He made a good landing with the intact arm.

All fractures about the wrist and of the fingers were caused by direct contact with the ground, particularly when the jumper, in error, lunged forward instead of tumbling to break the force of his fall.

Brachial plexus palsies.—The material at Fort Benning included only two instances of transient palsy of the brachial plexus, both transient and both caused by traction by the parachute. The same mechanism was apparent in the five similar cases, all from different companies, reported in considerable detail by Capt. (later Maj.) Victor H. Rosen, MC, from an

overseas hospital (*9*). The number of jumps ranged from three to 10. The history was clear cut in each instance. The symptoms had been present and disregarded for several weeks. They were the same in each case, chiefly paresthesias of the digits of one hand, with weakness of the fingers in two instances.

The injury in each instance apparently was incurred just after the jumper left the plane, when various twists and strains can be caused by the sudden pull of the risers if the body is in any but a vertical position when the chute opens. At this time, sudden upward strains on the shoulder could make the lower trunk or medial cord, if not the lower spinal roots themselves, susceptible to stretching injuries. This presumption was borne out in these five cases by the predominance of symptoms in the ulnar distribution in the hand.

Treatment consisted of physiotherapy, a short rest from actual jumping, and reassurance. An elaborate diagnostic workup was not recommended, as introducing a possible psychic factor; in all but one instance, neurotic gain from the symptoms seemed minimal if present at all. Removal from a duty status also was not considered.

Femur and knee.—About half of the fractures of the femoral shaft were caused by opening shock. The remainder were caused by excessively violent landings, but the spiral pattern almost invariably present also indicated an element of rotation. The Fort Benning experience showed that even the neck of the femur was not immune to external rotation stress. Injuries in this area represented the uppermost link in the chain of external rotation fractures.

Fractures of the patella, also infrequent, were caused by direct contact with the ground or by indirect force that caused sudden flexion of the knee. Most of the serious tears of the ligaments of the knee were caused by abduction stress during opening shock (fig. 59). External torsion was a definite factor in injuries of both the ligaments and the menisci. A special study of ligamentous injuries is described later in this chapter (p. 218).

Fibula and tibia.—Simple oblique fractures of the distal end of the fibula (fig. 60) were long recognized as the prototype of external rotation injuries. Either alone or in combination with other injuries, they were present in some two-thirds of the fractures of the lower extremity. As the toes hit the ground first, the foot, ankle, and knee were successively abducted by the external rotatory force of the angle drift.

Fractures of the shaft and head of the fibula, of course, might also be caused by direct trauma as well as by the element of torsion. The so-called silent parachute fracture involved the upper third of the fibula and was associated with such trivial symptoms, if any at all, that it was not unusual for the jumper to sustain it in the C stage of training and to proceed to the D stage before reporting for medical care. Such a relatively painless pathologic lesion could occur only because the fibula does not enter into weight-bearing. In one series of 35 silent fractures studied by Major

FIGURE 59.—Anteroposterior roentgenogram of both knees, showing abduction of leg on side with torn medial collateral and cruciate ligaments. This injury occurred when the suspension lines were caught around the extremity during the opening shock.

Lord and Colonel Coutts (4), only 10 jumpers reported for treatment at the time the injury was sustained. The others reported from 7 to 30 days later, with their only complaint slight pain in the upper, outer aspect of the leg. Many of the first roentgenograms showed considerable callus formation.

Fractures of the upper third of the fibula could easily be misdiagnosed if the possibility was not borne in mind. It is believed, in fact, that many were considered sprained muscles and not diagnosed at all. These fractures increased in frequency as the landing technique was changed and landing was accomplished with the feet and ankles held closely together, with a reduction in the frequency of fractures of the lower fibula.

An increase in dislocations of the fibular head also was noted with the change in landing technique, but the change was regarded as favorable

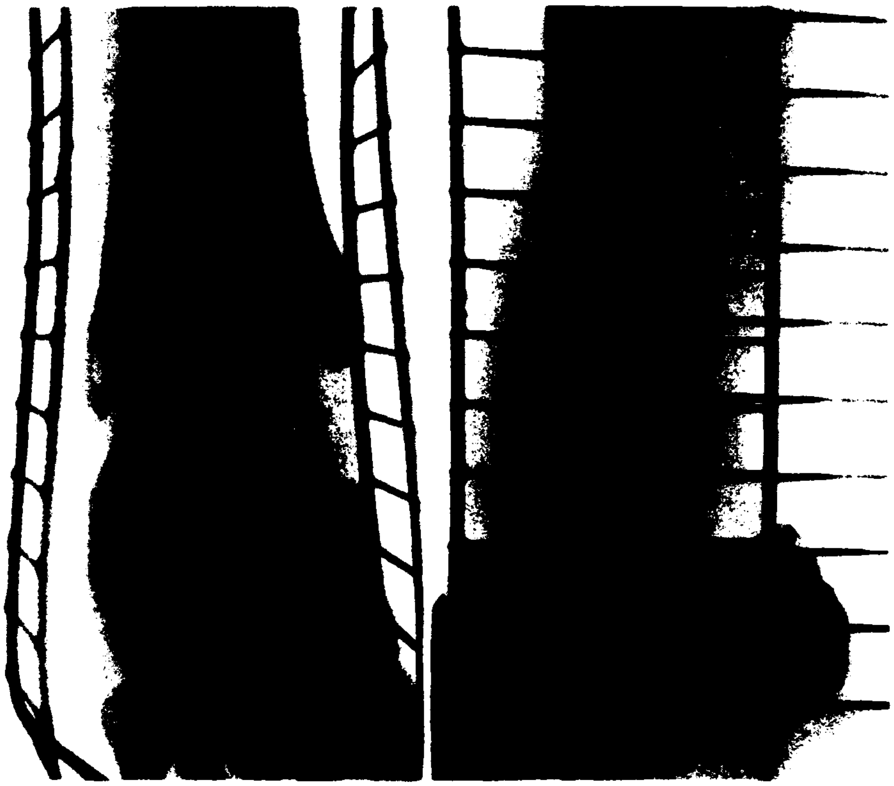

FIGURE 60.—Typical oblique fracture of distal end of fibula, with widening of ankle mortise, resulting from predominant external rotatory force. (Left) Anteroposterior roentgenogram of ankle and lower leg showing fracture of fibula and widening of mortise. (Right) Lateral roentgenogram showing fracture of fibula.

since a dislocation is easier to treat than a fracture and the convalescent time is substantially less.

Dislocations of the head of the fibula occurred in sideward landings associated with oscillations of the parachute (p. 192). They resulted from a tendency of the head to spring from its anatomic position. Although the attachment of the tendon of the biceps femoris theoretically would tend to dislocate the head posteriorly and upward, this type of dislocation was not observed at the Parachute School at Fort Benning. Anterior dislocation of the head occurred in eight cases, none associated with fractures. All the jumpers gave a history of rotational stress on landing, followed by pain in the lateral aspect of the knee.

Diagnosis of these dislocations was not difficult since the head of the fibula lies subcutaneously and is readily palpable. Peroneal nerve involvement was never observed; the relation of the peroneal nerve to the fibular head is such that no pressure is exerted on the nerve when the dislocation is only slight or moderate. Furthermore, reduction was accomplished so promptly in these cases—most often on the jump field by the ambulance

surgeon—that if pressure did exist initially, it was promptly relieved. One medical officer undergoing parachute training reported numbness of the foot for several days after dislocation of the fibular head, but he showed no tendency to muscle weakness or foot drop.

Treatment of these *dislocations* was by strong inversion of the foot, with direct pressure over the fibular head, followed by the application of an elastic bandage. The patient was kept ambulatory on crutches.

Isolated fractures of the fibula could occur anywhere along the shaft, or even obliquely through the head, and were often associated with diastasis of the tibiofibular syndesmosis. The association was so common that the presence of a high fibular fracture was an indication for an *investigation* of the ankle to search for the other half of the combination. The ligamentous lesion at the ankle was minor, but the dislocation in that area was sometimes so gross that it completely overshadowed the fibular fracture until the latter was found in the roentgenogram.

Another typical pattern took the form of spiral fractures of the shafts of the tibia and fibula (fig. 61), the tibia at the junction of the middle and lower thirds and the fibula, as a rule, at the upper third or through the neck. The torsional etiology of this injury had been thoroughly established before its parachute association by its occurrence in football, skiing, and other sports. The spiral pattern was characteristic of the failure of a brittle rod to withstand torsion stress. It was etiologically similar to an external rotation fracture of the foot or ankle, with the disruptive effect of the torsion manifested on a higher level. When only the tibia was fractured, the displacement was less severe than when both bones were broken, and the prognosis was better, since the intact fibula functioned as an internal splint.

The element of posterior thrust was responsible for still another typical parachute injury, the splitting off of the posterior tibial lip at the ankle joint (figs. 52 and 62). The injury was frequent among paratroopers, but by no means limited to them, as some observers were inclined to believe. Major Ciccone and Captain Richman traced its recognition back to 1909, when it was described by Meissner, and pointed out that it was "rediscovered" by Cotton in 1915 before it appeared in World War II as the paratrooper's fracture (*6*). It may appear in any circumstances in which the body falls forward as well as downward, as, for instance, when the heel catches on a step or curbing while the foot is in the equinus position. Since the usual civilian shoe is cut low, there is little or no support for the posterior structures of the ankle joint, and the injury is sometimes severe enough to require open reduction to reapproximate the fragments. In paratroopers, the injury was usually less severe, probably because of their high, tight-fitting boots. When they were worn, the astragalus could not be pushed forward to any appreciable degree, and while the posterior ligamentous structures were undoubtedly stretched and partly torn, their integrity was not usually compromised because the separation was not complete. If, how-

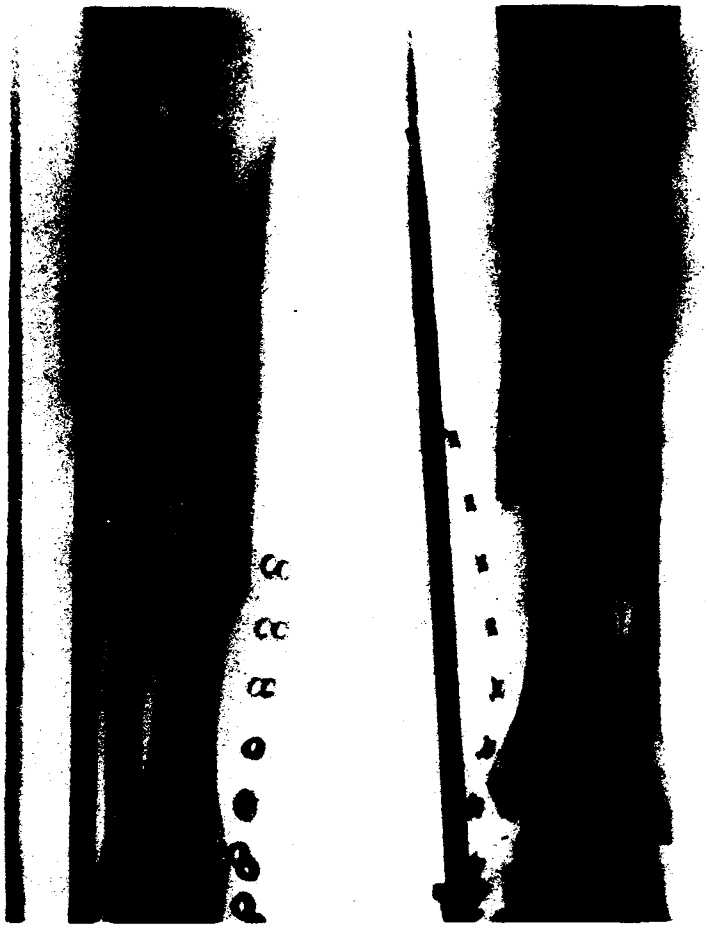

FIGURE 61.—Spiral fractures of tibia and fibula, another rotation-plus-thrust type of injury. (Left) Oblique roentgenogram showing spiral fractures of shafts of tibia and fibula. (Right) Anteroposterior view.

ever, the force was sufficient, a posterior dislocation of the ankle joint could occur.

Double fractures of the posterior lip of the tibia and the lower third of the fibula were the result of operation of a double force:

1. When the foot was rotated externally, the anterior border of the inner surface of the external malleolus forced it (the foot) outward and backward. If the inferior tibiofibular ligament remained intact, and if the force was sufficient, the result was an oblique fracture of the lower end of the fibula, about 2 inches above the tip.

2. A posterior force was also operative, resulting from the forward motion of the foot as it struck the ground. The impact was transmitted up through the metatarsals and the tarsus, and the posterior tibial lip was sheared off.

The mechanism just described had been advanced by Dolbnin in the prewar literature (p. 176) to explain the frequency of fractures of the posterior lip of the tibia.

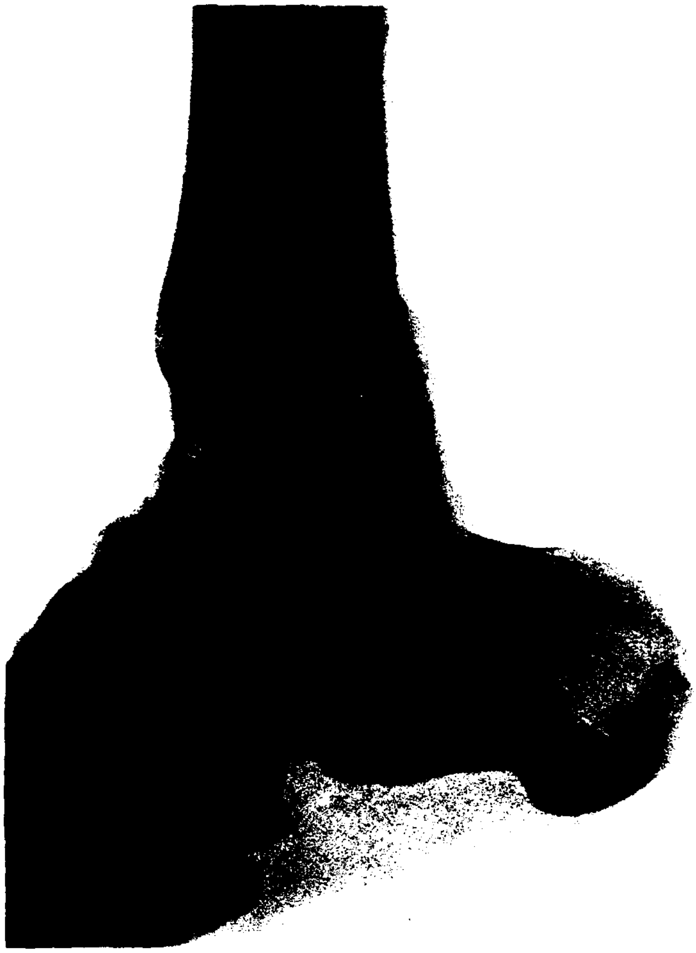

FIGURE 62.—Lateral rotentgenogram of ankle showing typical fracture of posterior tibial lip resulting from upward and backward thrust. As usual, there is no appreciable separation of the fragments.

Another variant of these fractures was the trimalleolar fracture described by Lewin (*10*), which involved the internal and external malleoli as well as the posterior lip of the tibia (fig. 42). It was less frequent than fractures involving only the fibula and the posterior tibial lip.

Whether a fracture of the posterior tibial lip occurred alone or in combination with a fracture of the external malleolus, the treatment was immobilization of the joint for about 4 weeks. A skintight plaster cast was used, with a walking iron. Incomplete fractures required less time for healing. In trimalleolar fractures, weight-bearing was deferred, to avoid separation of the malleolus.

Jumpers with uncomplicated fractures of the posterior tibial lip were allowed to return to training after an adequate period of convalescence, which was seldom less than 3 months. Those with fractures involving other regional structures were recommended for permanent nonjump status.

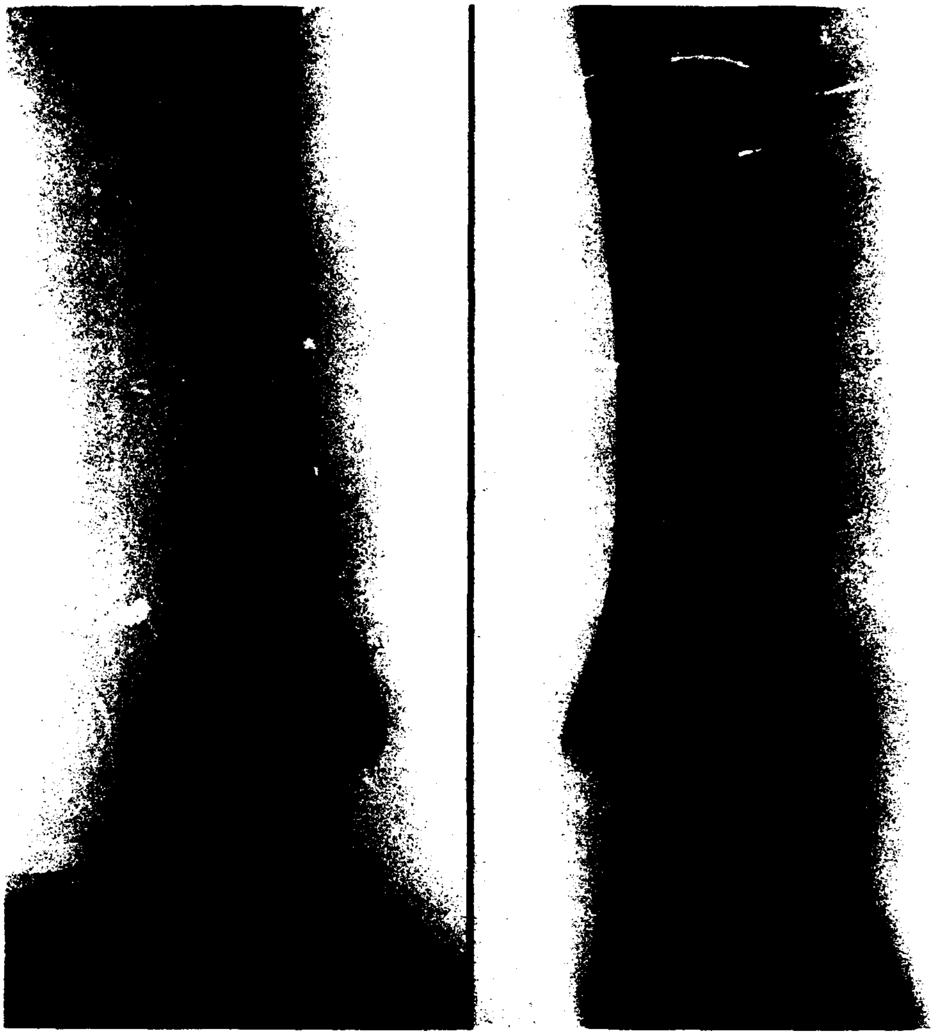

FIGURE 63.—Posterior dislocation of right ankle and fracture of posterior lip of tibia. This injury was the result of two forces, lateral torque and upward and backward thrust. (Left) Lateral roentgenogram of ankle showing dislocation and fracture. (Right) Anteroposterior view of same, showing fractures of medial malleolus and lower shaft of fibula.

Ankle.—Not much more remains to be said about fractures of the ankle. They represented the largest number of parachute fractures in any single location. The great majority were in the lateral malleolus. The mechanism was generally the same as the mechanism that produced simple sprains of the ankle; namely, adduction and inversion of the foot, with an uneven distribution of the weight, more being put upon the foot that touched the ground first. The character of the injury that resulted after landing varied. If the force was not very severe, a sprain would result. If the force was more severe, there were three possibilities:

1. If rotatory force predominated, an oblique or spiral fracture of the lateral malleolus would ensue.

2. If upward and backward thrust predominated, simple shearing off of the posterior tibial lip of the ankle mortise might be expected.

3. If the causative forces were about equal in their traumatic effect, there would be fractures of the lateral malleolus and of the posterior lip of the tibia (fig. 63).

These three types of fractures of the ankle recurred so frequently and so characteristically that they could reasonably be regarded as more than fortuitious and as true parachute fractures.

Bimalleolar and trimalleolar fractures, as well as simple fractures of the medial malleolus, resulted from less frequent combinations of forces and of variations in the landing impact.

Pure external rotation injuries were uncommon except for avulsion fractures of the posterior process of the talus, caused by excessive tension of the talofibular ligament. This strong structure, which fastens the fibula against the side of the talus, ordinarily is highly resistant to injury. Under external rotary stress, however, it occasionally avulsed its bony insertion. The resulting fragment resembled an os trigonum tarsi.

Ligamentous injuries caused by external rotation were very common in the ankle, not only as complications of malleolar fractures but also as solitary lesions of major significance in their own right. Tears of the deltoid ligament and of the internal tibiofibular ligament were most important.

Foot.—Landing thrust injuries of the foot took the form of dislocation of the great toe; fracture of the flexor sesamoid; impaction of the metatarsals; and crushing of the mid tarsal bones, especially the navicular, which frequently was shattered by the hammerlike head of the talus under the terrific impact of landing.

Fractures of the metatarsal neck often were multiple. The heads were sheared off and displaced upward and laterally (fig. 64), as a direct result of upper and forward thrust and the force of lateral rotation. It was not uncommon to see, in association with fractures of this type, a compression of the cuboid, or of the cuboid facet of the os calcis, as the result of further transmission of the landing force through the metatarsals. Reduction could be accomplished by reversing the mechanism of injury; that is, by manipulating the metatarsal heads downward and medially.

Other fractures in the foot, notably those of the scaphoid, were caused by direct posterior thrust through the metatarsals, as a result of which the scaphoid was crushed between the head of the astragalus and the cuneiform bone (fig. 65). Some comminuted tarsal scaphoid fractures apparently were due to the same mechanism as fractures of the posterior tibial lip (p. 176).

Fractures of the os calcis were the result of direct landing force. Most of them were minor, usually presenting as incomplete linear fractures and chip fractures.

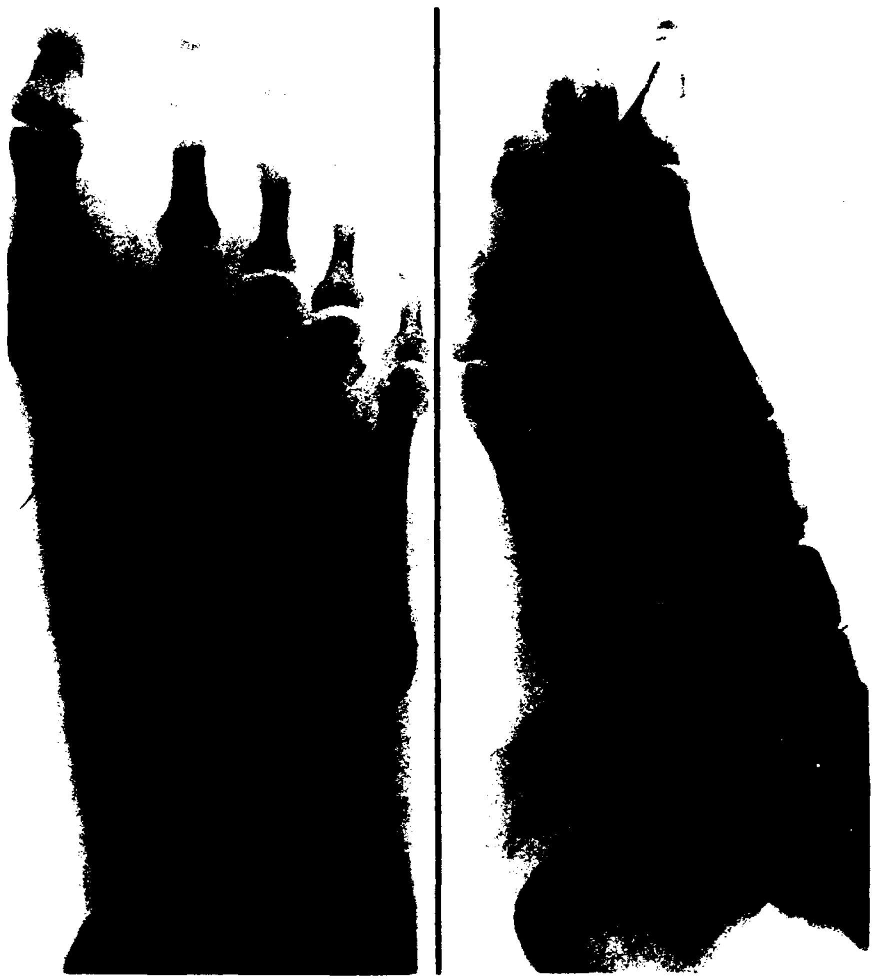

FIGURE 64.—Fractures of metatarsal heads. Fractures of this type demonstrate the landing impact expended on the metatarsal necks as the direct result of upward and forward thrust and the force of lateral rotation. (Left) Anteroposterior roentgenogram of right foot showing fractures of second, third, and fourth metatarsals just proximal to their heads. (Right) Oblique roentgenogram showing same.

Ribs.—Fractures of the ribs were caused by trauma to the chest wall from the shock of the opening parachute or by direct contact with the ground.

Spine.—Fractures of the vertebral bodies were of the compression type and were always caused by the same mechanism: When the jumper assumed the classical jackknife position (p. 197), either he landed on his feet and then fell back into the sitting position or he was pulled backward by the parachute and landed on his buttocks or his back. These fractures were serious enough to put jumpers on permanent nonjump status.

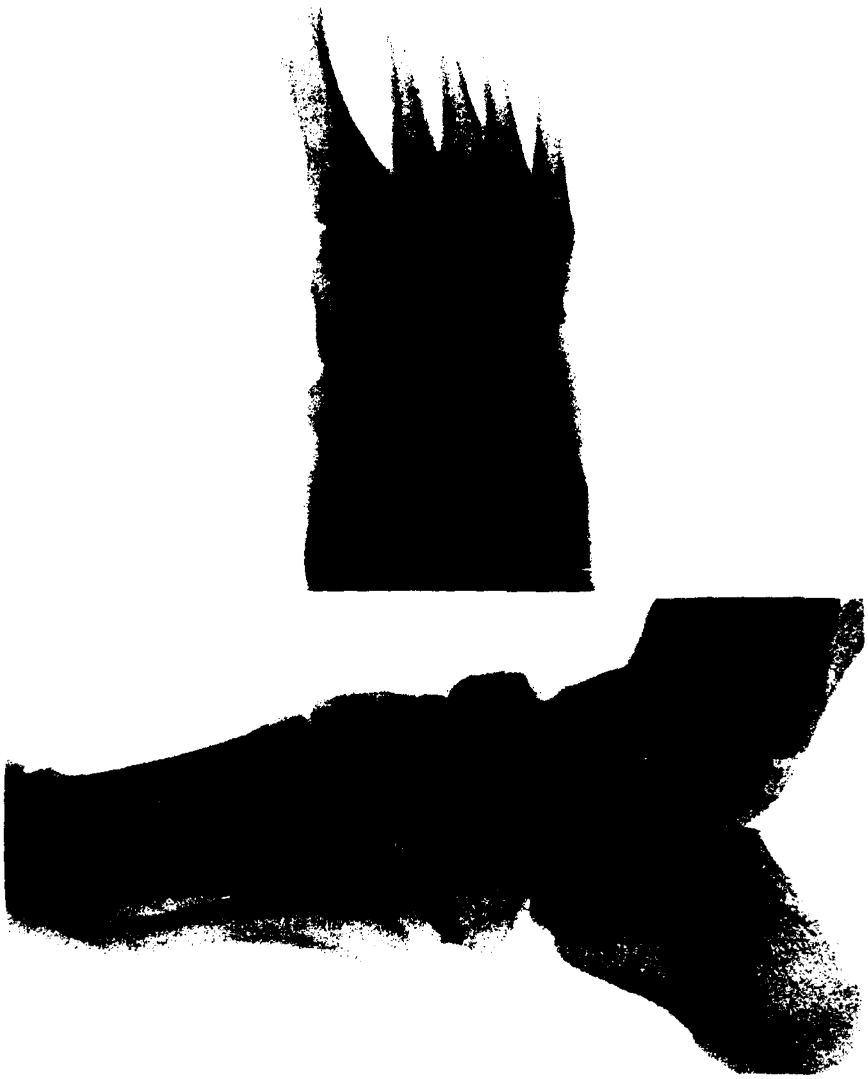

FIGURE 65.—Typical crushed scaphoid with displacement resulting from direct posterior thrust through metatarsals. (Top) Anteroposterior roentgenogram of foot showing fracture of scaphoid bone with some medial displacement. (Bottom) Lateral roentgenogram showing more clearly fragmentation of scaphoid bone with obvious dorsal displacement.

Two fractures in this series which resulted in paraplegia occurred, respectively, at the level of the fifth and sixth cervical vertebrae when jumpers attempted to tumble, but instead landed on their heads.

ACUTE INSTABILITY OF THE LIGAMENTS OF THE KNEE

Over a 3-year period at the Parachute School at Fort Benning, Captain Richman and Lt. Kenneth O. Barnes, MC, studied intensively 85 cases of

FIGURE 66.—Convenient position for eliciting abduction instability with patient completely relaxed. (Richman, R. M., and Barnes, K. O.: J. Bone & Joint Surg. 28: 473–490, July 1946.)

what they termed *"acute instability of the ligaments of the knee,"* in most instances (67) the result of parachute injuries (*11*). Their purpose was twofold, to describe the previously undescribed mechanism of injury in these cases and to report the results of conservative management.

The literature on the subject of injuries to the ligaments of the knee was remarkable at this time, the authors noted, for its contradictions and divergent statements on all phases of the subject, including the surgical anatomy. There was, however, a consensus on the following points:

1. The knee should be considered as a total functional unit.
2. It is a complicated weight-bearing joint, with combined hinge, gliding, and rotary action.
3. It is supported by active muscle power and by ligaments which also serve to direct the muscle power.
4. The ligaments of the knee are mutually reinforcing and function as a team. Solitary ligaments are seldom injured, but if they should be, the loss of a single ligament will not produce major instability.

Materials and Methods

This investigation was carried out on the fundamental concept, just stated, that the knee is a functional unit (Palmer's "physiologic joint") (*12*).

No injury was included in the series unless abnormal mobility could be demonstrated clinically. Such conditions as sprains, dislocations of the

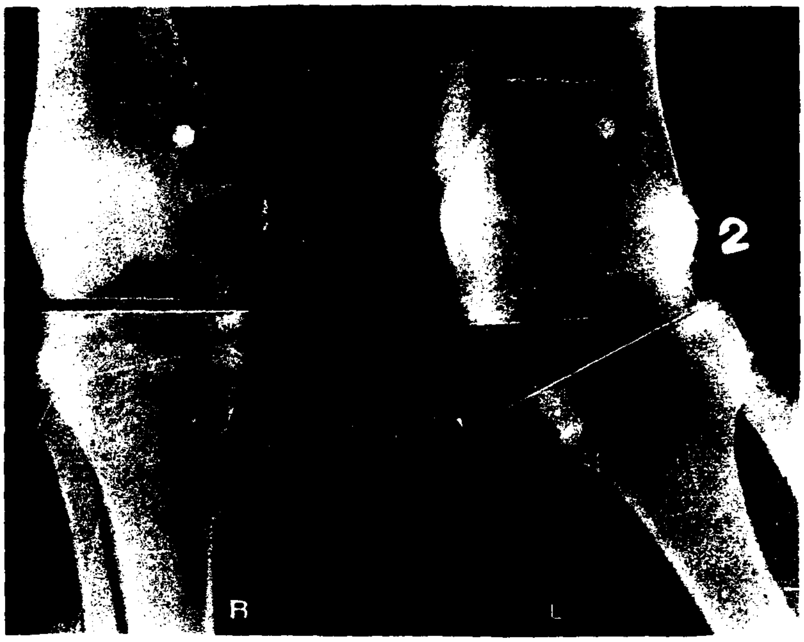

FIGURE 67.—Anteroposterior roentgenogram demonstrating technique of measurement of severe abduction disability of left knee, as compared with normal right knee, immediately after injury.

patella, ordinary tears of the meniscus, fractures of the tibial plateau, and effusions without instability were not included.

Uniformity of observation was secured by systematizing the technique of examination and by strict adherence to objective standards. The precise technique of examination was important, since the demonstration of abnormal mobility determined not only the diagnosis but also treatment and prognosis. Stability was evaluated in terms of total functional loss, ligaments were not evaluated individually. Abduction instability, the type most frequently encountered, was measured first in semiflexion (fig. 66), the position of effort, and then with knee extended to the normal standing position. Relaxation of the thigh muscles during examination was essential. Adduction instability was then similarly estimated. The knee was tested for genu recurvatum, and anteroposterior instability was measured in 90 degrees of flexion.

If the knee was too painful to permit adequate relaxation the examination was conducted under low spinal anesthesia, achieved by 50 milligrams of Novocain. This dosage was sufficient to abolish pain and reflex muscle spasm, but enough voluntary muscle power was preserved to facilitate the later application of a cast. With the patient thus relaxed, the knee was tested for all types of instability and was flexed through a full range of motion to rule out organic block. If necessary, fluid was aspirated.

The degree of instability was determined by measuring the degree of angular widening of the affected joint space as compared with that of the opposite, intact knee (fig. 67). To facilitate measurements, an adjustable hinged frame was constructed, on which the thighs were strapped together; roentgenograms were made while the legs were abducted simultaneously.

FIGURE 68.—Paratrooper's left boot, showing brush burns after exit from plane and descent. (Richman, R. M., and Barnes, K. O.: J. Bone & Joint Surg. 28: 473–490, July 1946.)

Consistency in reporting results was further assured by the fact that Captain Richman and Lieutenant Barnes personally treated 68 of the 85 patients in the series and followed their progress at monthly intervals as long as they remained at Fort Benning.

Criteria of evaluation of posttreatment instability will be discussed later.

Of the 67 parachute injuries, 59 were caused by opening shock and eight by landing impact. The other 18 injuries were sustained on obstacle courses (nine), in sports (five), and in miscellaneous circumstances (four).

Of the 67 parachute injuries, 56 were on the left side, the explanation being that the C–47 plane used in training had only a single exit, on the port side. There was no explanation for the fact that 11 of the 18 injuries due to other causes were also on the left side.

The predominant instability was of the abduction type in 80 cases, of the adduction type in three, and of other types in two.

Mechanism of Injury

A study of these 67 cases revealed the following mechanism of injury, which was concurred in by experienced instructors at the Parachute School

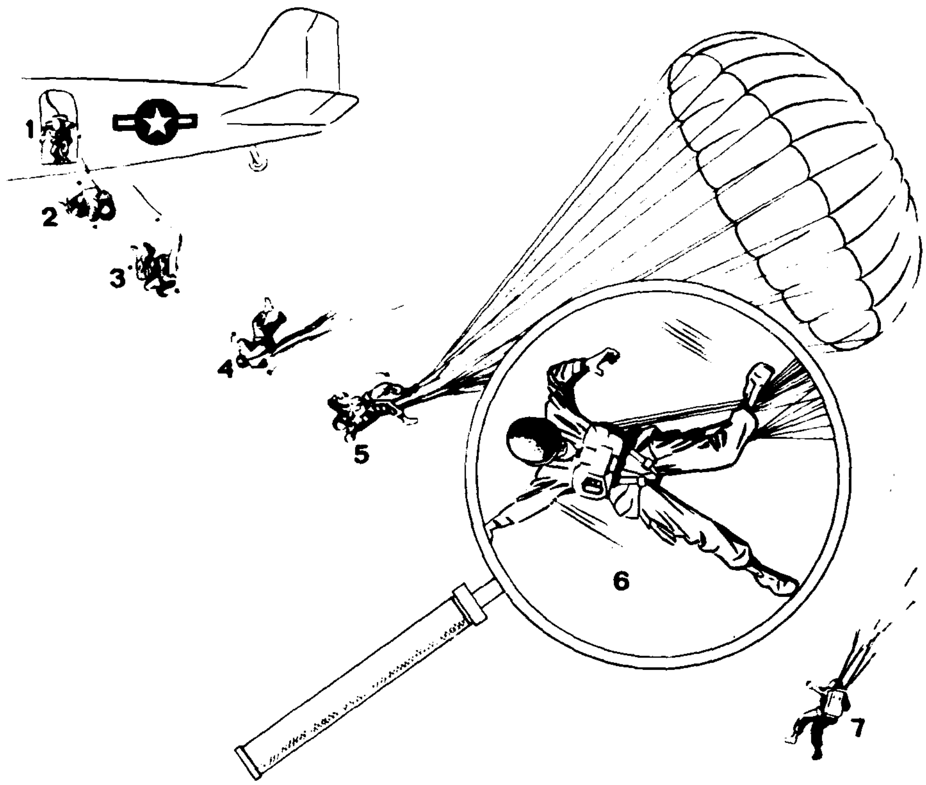

FIGURE 69.—Diagrammatic sequence of events in parachute injury caused by opening shock. At phase 6, the left leg is abducted by the taut suspension lines and a tear of the medial collateral ligaments results. (Richman, R. M., and Barnes, K. O.: J. Bone & Joint Surg. 28: 473–490, July 1946.)

and was further confirmed by the presence of brush burns on the left boot (fig. 68): The paratrooper, instead of leaving the plane in the approved feet-first, feet-together position, dived out headfirst and was carried by his own momentum into a left oblique somersault (fig. 69). As he tumbled forward, his left leg became entangled in the slack suspension lines of his parachute. When the canopy snapped open in midair, the left knee was wrenched violently upward and sideways, and excruciating pain was experienced. The jumper believed that his knee was dislocated. He usually managed to land with his weight on the uninjured limb, without much additional pain, and either limped away or was picked up by aidmen on the field.

Diagnosis and Clinical Picture

Although the pathognomonic feature of injuries of the ligaments of the knee was abnormal mobility (instability) of the knee, in most cases in this series this finding was overlooked in the original examination, and the initial diagnosis was internal derangement of the knee or traumatic syno-

vitis. Neither diagnosis carried any hint of the serious ligamentous damage that had occurred. The error was readily comprehensible; the knee was frequently too painful to permit deliberate testing for instability, or the instability was masked by muscle spasm or effusion. The correct diagnosis could be made, however, by bearing in mind the following characteristic features of ligamentous instability:

1. The patient gave a history of severe, direct violence, in contrast to the minor, almost trivial injuries that usually caused lesions of the menisci.
2. He walked guardedly, if at all, and typically complained that his knee buckled inward if he made a misstep.
3. He observed his footing carefully, and when moving to the examining table, he cradled the injured limb over the intact limb.
4. Physical examination revealed local soft-tissue swelling, tenderness, and often ecchymosis over the tibial collateral ligament, usually most marked at the femoral insertion.
5. In recent, severe injuries, the torn ligament was often palpable as a loose, tender subcutaneous mass along the course of the tibial collateral ligament.
6. Full extension of the knee was prevented by pain and spasm, not by organic block, as with dislocated menisci.
7. Intra-articular fluid varied in amount. Smaller quantities accumulated in the more severe injuries because there was opportunity for drainage through the capsular tear into the soft tissues.

Management

Treatment of ligamentous instability was based on Böhler's dictum that the ligaments of the knee, like all similar structures, will unite satisfactorily if they are immobilized long enough in the proper position (*13*). These patients were immobilized in plaster from toes to groin, with the knee in the varus or other corrective position, depending upon the degree of instability, and in about 30 degrees of semiflexion. This position was comfortable and also took major tension off the capsule and the cruciate and collateral ligaments. The cast was applied in two sections, the lower half being allowed to harden before the knee and thigh portion was incorporated in it. This technique permitted easier control of the unstable knee and assured accurate alinement of the joint.

The duration of immobilization depended upon the severity of the injury. As a rule, the knee was stable enough to permit weight-bearing in 3 to 4 weeks. The original cast was then replaced by a snug walking cylinder, which held the knee in 5 degrees of flexion and which was worn for another 3 to 5 weeks. Immobilization was usually necessary for 5 to 6 weeks, but seldom for more than 10 weeks.

The only support used after removal of the second cast was a Thomas heel with quarter-inch medial wedges. Bandages and adhesive tape strapping furnished no support for weight-bearing limbs; they simply limited the range of motion and promoted further muscle atrophy. Hinged casts and braces were considered futile as well as unphysiologic.

Exercises were mandatory from the beginning of treatment and were intensified as soon as the cast was removed. Each patient was required to devote an hour a day to supervised quadriceps exercises, beginning with simple flexion and extension of the knee in bed, followed by knee bends, leg-raising, chair-climbing, weight-lifting, running, and cross-country bicycle rides to the limit of the patient's endurance. Pain was not considered a contraindication to exercise per se. The only valid reason for suspending or even decreasing the routine was soft-tissue induration or a chronic accumulation of fluid in the joint, which was increased by a provocative test. The more effort by the patient, the more rapid was his recovery. There was remarkably close correlation between the recovery of the thigh musculature and the functional capacity of the knee.

The patient was assigned to limited duty for at least 6 months after the injury, and longer if necessary to assure complete healing.

Evaluation of Results

The posttreatment functional capacity of the knee was evaluated in terms of 12 specific clinical criteria (table 7), so that the analysis would be as objective and as impersonal as possible:

1. Pain. The patient was questioned specifically regarding pain on twisting movements, aching at night after prolonged exercise and activity, and pain in inclement weather. Individual pain tolerance was necessarily a factor in the replies.

2. Endurance, estimated objectively on the basis of measured performance. Endurance in a young person was not considered normal unless he could walk 12 to 15 miles.

3. Agility, as distinguished from endurance. Patients frequently were encountered who could work all day standing but could no longer run or engage in sports.

4. Quadriceps atrophy. The measurements, taken at mid thigh, included all the regional muscles, but clinically the quadriceps manifested more atrophy than others, and its recovery was the most reliable single index of functional recovery. Patients with shrunken thighs invariably complained of easy fatigue, diffuse pain in the knee, and buckling sensations (Palmer's weak-knee syndrome) (*12*). Clinical experience showed that atrophy in excess of three-fourths of an inch almost invariably was associated with symptoms. If it approached 1½ inches, there was extreme disability, even if the ligaments had healed well. In this series, the average cooperative patient showed full quadriceps recovery in 5 to 7 months. In six cases, there was more than 1 inch of atrophy at the end of 6 months, and in three of them, the only explanation was the patients' own laziness and neglect of prescribed exercises. With proper supervision and more intensive exercises, all three developed greater endurance and agility, and had freedom from pain.

5. Subjective instability, graded according to complaints of "slipping," "getting out of place," or "buckling" of the knee, with due consideration of the antecedent activity.

6. Sagittal instability, also termed anteroposterior instability or "drawer" action (p. 675).

7. Abduction instability in semiflexion. This factor was measured roentgenologically, with the limb forcibly abducted and the knee in 15 degrees of semiflexion.

TABLE 7.—*Clinical criteria and quantitative ratings for evaluation of postinjury functional capacity of knee, Parachute School, Fort Benning, Ga.*

Criterion	Quantitative rating			
	1	2	3	4
Pain	None	Slight	Moderate	Severe.
Endurance	Normal	Walk of 5 to 10 miles; slow trot of 1 mile.	Walk of 3 to 5 miles; slow trot of ½-mile.	Walk of less than 3 miles.
Agility	Normal	Cross-country running; short-stop sports; few symptoms.	Cross-country walking; can run on level ground.	Cannot run on level ground.
Quadriceps atrophy	None	Up to ½-inch	¾ to 1¼ inches	1½ inches or more.
Subjective instability	None	Slight	Moderate	Severe.
Sagittal instability	None	0 to 4 millimeters	5 to 10 millimeters	Over 10 millimeters.
Abduction instability in semiflexion.	None	0 to 4 degrees	5 to 10 degrees	Over 10 degrees.
Abduction instability in extension.	None	0 to 2 degrees	3 to 5 degrees	Over 5 degrees.
Intra-articular fluid	None	Slight and transient	Slight and chronic, or moderate and transient.	Marked or persistent.
Clicking	None	Slight or intermittent clicking.	Moderate and persistent.	Painfully severe and constant.
Range of motion	Normal	Flexion to 140 degrees	Flexion to 120 degrees	Less than 90 degrees of flexion.
Determination and attitude.	Normal	Less than optimum effort and perseverance.	Discouraged and uncooperative.	Markedly defective attitude; exaggerated disability.

Source: Richman, R. M., and Barnes, K. O.: Acute Instability of the Ligaments of the Knee as a Result of Injuries to Parachutists. J. Bone & Joint Surg. 28: 473–490, July 1946.

8. Abduction instability with the knee in extension. This factor was also measured roentgenologically, with the patient in the normal standing position.

Recovery of stability of the knee was naturally the first consideration of treatment though it did not, in itself, determine the functional result. In abduction injuries, healing was very satisfactory. In the last 60 consecutive cases in this series, roentgenographic measurements showed that 57 patients had recovered with less than 5 degrees of residual abduction disability. Even the most extreme abduction injuries, with apparently complete rupture of the tibial collateral ligament, showed only 2–3 degrees of residual instability. Minor degrees of instability were tolerated very well and did not interfere appreciably with the patient's endurance or agility. Only when residual abduction instability exceeded 5 degrees did symptoms become troublesome. Then, they included weakness, recurrent effusions, and pain, all usually of such a degree that the man was no longer fit for military service.

Results in other forms of instability were equally good, but the numbers were too small to be significant. Residual adduction instability proved relatively less disabling than the abduction variety because of the closer anatomic supporting action of the tensor fasciae latae and the iliotibial band (fig. 70). In the more pronounced cases of anterior and posterior instability, with more than 1 centimeter of drawer action, the patients complained of slipping sensations, but symptoms were not generally troublesome unless abduction weakness was also present.

9. Intra-articular fluid, with both the amount and the frequency of recurrence considered. Fluid usually disappeared within 4 to 6 months after injury and did not

FIGURE 70.—Extreme adduction-plus-recurvatum instability of right knee due to avulsion of lateral collateral ligament. (Left) Anteroposterior roentgenogram of knee showing 27 degrees of adduction. (Right) Lateral roentgenogram showing 30 degrees of hyperextension (recurvatum). Conventional roentgenograms in this case showed only soft-tissue swelling. Special positioning was necessary to demonstrate the pathologic process. (Richman, R. M., and Barnes, K. O.: J. Bone & Joint Surg. 28: 473–490, July 1946.)

recur, but in a few instances, it persisted and fluctuated with the amount of physical activity. These patients also presented poor intrinsic stability, chronic thickening of the capsular structures, and excessive quadriceps atrophy. They were unusually susceptible to further injuries, and effusions tended to recur even with minor sprains. Careful rehabilitation of the thigh musculature minimized episodes of effusion and improved functional capacity.

10. Clicking, the term including various cracking and snapping sounds. No true locking was observed in this series.

11. Range of motion, measured in degree of flexion, beginning with 0 at full extension. Almost all of the patients recovered complete extension and normal flexion within 6 months, and ultimately every patient but one, who had a dislocated knee, obtained at least 135 degrees of flexion, which is sufficient for all ordinary pursuits.

12. Determination and attitude. The patient's perseverance, cooperation, and will to recover were highly important. In the Army, and in civilian industry, the secondary gain derived from disability sometimes influenced and postponed ultimate recovery.

The criteria included in this list were considered representative. They were chosen because they were thought to furnish an integrated picture of functional recovery of these damaged knees. By measuring the criteria objectively, in numerical units, according to rigid clinical standards (table

FIGURE 71.—Serial roentgenograms of right knee showing development of typical Pellegrini-Stieda calcification after abduction injury. (Left) Three weeks after injury. (*Right*) *One year after injury.* Clinically, a slight prominence at the site of calcification occasionally became tender after direct trauma, but this patient, an instructor of the Parachute School, was very active, had no symptoms, had good stability of the knee, and had no limitation of motion. (Richman, R. M., and Barnes, K. O.: J. Bone & Joint Surg. 28: 473–490, July 1946.)

7), inconsistencies likely to arise from the personal equation were reduced to a minimum.

A common roentgenographic finding while ligamentous healing was proceeding was the development of calcific shadows along the course of the medial collateral ligament (Pellegrini-Stieda disease (p. 734)). This condition (figs. 71 and 72) was present in almost 60 percent of these cases. Typically, 3 to 6 weeks after injury, a flocculent shadow appeared (fig. 71), which gradually condensed to a curvilinear residue, associated more or less closely with the femoral attachment of the tibial collateral ligaments. There was sometimes persistent tenderness of the site of calcification, and an occasional patient complained of slight pain, but no actual disability was attributable to the lesion, and it was considered of roentgenologic rather than clinical importance.

SUMMARY OF EXPERIENCE

In spite of the great increase in the number of jumps at the Fort Benning Parachute School as the war progressed, there was a considerable

FIGURE 72.—Anteroposterior roentgenogram of knees showing very slight residual instability of left knee 3 months after injury. Note pronounced calcification, still in evolutionary stage, of medial collateral ligament. At the end of 5 months, this patient rejoined his former organization and soon thereafter made three jumps. Except for persistent local tenderness the calcification, still present at this time, caused practically no disability. (Richman, R. M., and Barnes, K. O.: J. Bone & Joint Surg. 28: 473–490, July 1946.)

and steady decrease in the rate of injury. During the first year of operation of the school, the jumper had about a 5-percent chance of injury during some stage of training. By the end of the war, he had about an 0.4-percent chance of being hurt in any single jump.

For this improvement, there were certain clear-cut reasons:

1. The increasingly strict criteria used in the selection of candidates for the school.

2. The exacting supervision of all students and the prompt elimination of unfit candidates, preferably during stage A of training.

3. The liberal use of sawdust on landing areas and drop fields.

4. Modifications in landing techniques.

5. Careful attention to the maintenance of all equipment and training aids.

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CHAPTER VI

Other Training Injuries

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

MATERIALS

Training injuries have constituted an important medical problem in every war of modern times. They constituted such a problem in World War I. In that war, however, they were of rather limited importance because of the relatively small number of men engaged, the brief duration of U.S. involvement, and, at least in retrospect, the relative softness of World War I training as compared to those factors (number of men, duration of war, harshness of training), in World War II. The 17-week training cycle of World War II, which was reduced later to 14 weeks, imposed critical problems for orthopedic surgeons which did not exist in World War I, in which training in the United States was limited to 6 to 8 weeks and the deliberate harshness of World War II training did not exist.

The material on which this chapter is chiefly based is derived from the following extensive, especially prepared reports:

1. A report by Maj. Louis W. Breck, MC, Regional Hospital, Camp Swift, Tex. (*1*).
2. A report by Capt. (later Maj.) Samuel H. Nickerson, MC, Regional Hospital, Camp Maxey, Tex. (*2*).
3. A report by Maj. Patrick C. Doran, MC, Station Hospital, Fort Jackson, S.C. (*3*).
4. A report by Maj. David Sloane, MC, 97th General Hospital, Fort Bragg, N.C. (*4*). This report was limited to injuries incurred on obstacle courses.

GENERAL CONSIDERATIONS

Orthopedic injuries were numerically greater than training injuries of any other type, but their precise number is impossible to arrive at. Major Breck (*1*), pointing out that his figures were only approximations (though he believed them to be close to the true figures), produced the following statistics for the regional hospital at Camp Swift.

During 1944, the total daily average of troops at this camp was approximately 28,000. The total number of admissions to the hospital over the same period was

15,319. The average number of visits per month to the orthopedic clinic was 1,650. Of the patients seen daily, 60 percent were seen for the first time; the remainder were making return visits. Clinically, 30 percent of the patients complained of low back pain and another 30 percent complained of foot disabilities. Specific training injuries during 1944 included 33 fractures of the metacarpals, 18 of the metatarsals, 13 of the shaft of the tibia, nine of the shaft of the femur, 13 of the carpal scaphoid, four Colles' fractures, and four fractures of the spine.

During 1945, Major Nickerson (*2*) reported from Camp Maxey 17,763 visits to the orthopedic clinic, 9,798 by new outpatients, 589 by hospital patients, and 7,376 by former patients. Of these patients, it is known that 466 were hospitalized; 3,197 were reclassified; 2,955 were referred to the Clothing and Equipment Repair Shops, and 3,891 were returned to duty. The remainder were referred to other services.[1]

TRAINING CAMP RESPONSIBILITIES OF ORTHOPEDIC SURGEONS

Orthopedic surgeons assigned to training camps had special responsibilities (*3*). They included:

1. Assisting unit surgeons in maintaining trainees on full duty.
2. Prompt recognition of actual or potential disabling factors in trainees, so that those affected could be reassigned or separated from service.
3. Institution of treatment for training injuries, with the goal of reducing time lost from duty without jeopardizing the trainees' prompt recovery.
4. Application of accepted fundamentals of treatment promptly and efficiently to all injuries or diseases falling within the designated scope of military orthopedic surgery.
5. Thorough utilization of the reconditioning program in all phases of convalescent training injuries or diseases.

The orthopedic clinic in any Army hospital was always a place of great activity. This was doubly true on a large training post, on which a very large volume of orthopedic training injuries had to be handled with speed and dispatch, without compromising standards of orthopedic surgery and also without compromising the sound treatment that was the right of all injured trainees.

The diagnosis of training injuries was usually a simple matter. Perhaps one patient in every hundred presented some difficulty, and perhaps one patient in every thousand presented a genuinely obscure problem. Diagnostic error was infrequent, one reason being the routine of referring patients with sprains and contusions about which there was the least doubt —and often when there was no doubt—for roentgenologic examination.

The officer in charge of the orthopedic clinic had four chief diagnostic responsibilities:

1. To diagnose acute injuries sustained in training.
2. To differentiate chronic conditions that were EPTI (existing prior to induction)

[1] In connection with these figures, Major Nickerson reported 108 march fractures observed at a satellite station (Camp Fannin, Tex.), though none were observed at Camp Maxey, or at Camp Howze, Tex., in spite of a diligent search for them. His explanation was that the hilly terrain at Camp Fannin must have altered the mechanics of the foot so appreciably as to produce what amounted to an insufficiency state, which, contrary to the usual anatomic distribution of march fractures, practically always involved the first metatarsal bone (p. 186).

and were disabling (whether or not in line of duty) from similar conditions minor enough to be compatible with military service.

3. To differentiate remediable conditions in which the prognosis for correction by therapy was reasonably good from irremediable conditions, for which the only solution was separation from service.

4. To recognize the trainee who was simulating his symptoms in toto or was exaggerating his disability. The number of malingerers was not large, but minor disabilities were sometimes used by unscrupulous soldiers as a means of securing lighter types of duty, escaping combat duty, or securing transfers to organizations in which hardships would be fewer.

The newly inducted medical officer had to be constantly on his guard, until he became oriented in military medicine, to avoid the pitfalls inherent in the responsibilities just listed. He had to learn these lessons while he was handling a large volume of patients in a very short time. It was not always easy to overcome civilian habits of thought and practice. Once he was properly oriented and indoctrinated, however, and was alert to all the possibilities, his diagnostic errors were surprisingly few.

In view of the original inexperience in military medicine of many of the orthopedic surgeons in charge of clinics in training areas, it was essential that chiefs of sections recognize that the indoctrination and orientation of these young officers were an indispensable part of their duty. The visits of service command Consultants in Orthopedic Surgery and of the Consultant in Orthopedic Surgery, Surgeon General's Office, were most useful in keeping the staff informed of clinical and administrative policies. It was also most important that all concerned be kept informed of the frequent directives, medical bulletins, circulars, and other material dealing with clinical and administrative policies, issued from the Surgeon General's Office. Constant alertness was necessary because the picture changed so frequently during the course of the war.

Once these young medical officers were properly oriented and indoctrinated, it was remarkable how quickly their attitudes changed. Originally, they had wanted to manage all the injured trainees by the means—often the radical means—which they would have used in civilian life. They usually ended with attitudes of steady conservatism, reserving radical treatment for those patients in whom a good result could be practically assured after surgery, and exercising great care in the selection of patients for elective surgery (p. 102).

One lesson that a young medical officer promptly learned was that his problems in clinics handling training injuries often were far more administrative than diagnostic. In one sense, every orthopedic patient seen in the clinic was a disposition problem. His disposition had to be carefully weighed, in order to carry out the function of the Medical Department, that is, to conserve the fighting strength of the Army, while at the same time the rights of the patient were safeguarded. Special care was needed in men whose orthopedic disability was associated with a large functional overlay.

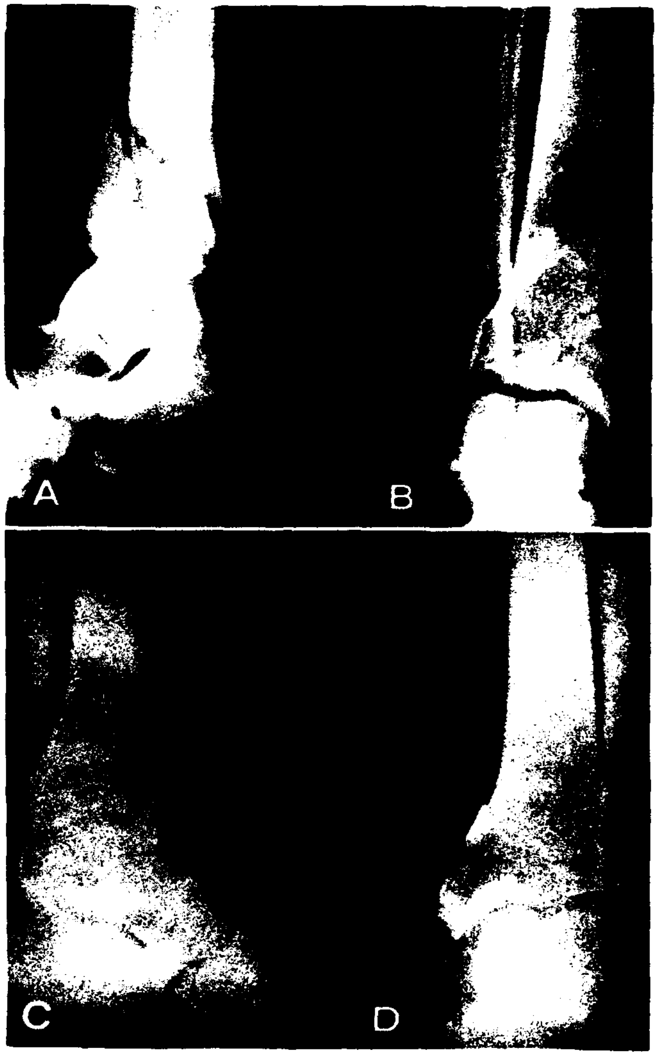

FIGURE 73.—Typical training injury: comminuted fracture of tibia just above ankle. (Top) Lateral and anteroposterior roentgenograms immediately after injury showing badly comminuted fracture. (Bottom) Lateral and anteroposterior roentgenograms after 8 weeks' treatment in balanced suspension with Kirschner wire traction. This casualty returned to full duty. Comminuted fractures of the distal end of the tibia were best treated with skeleton traction through the heel and in balanced suspension. (Breck, L. W.: Orthopedic Problems in Troop Training. [Unpublished data.])

The incidence of self-inflicted wounds in training camps, while not excessive, was still too large, and it persisted at the same level until late in 1944. Then, after the Federal Bureau of Investigation had been called in to investigate the situation, there was a sharp decline in such injuries. By

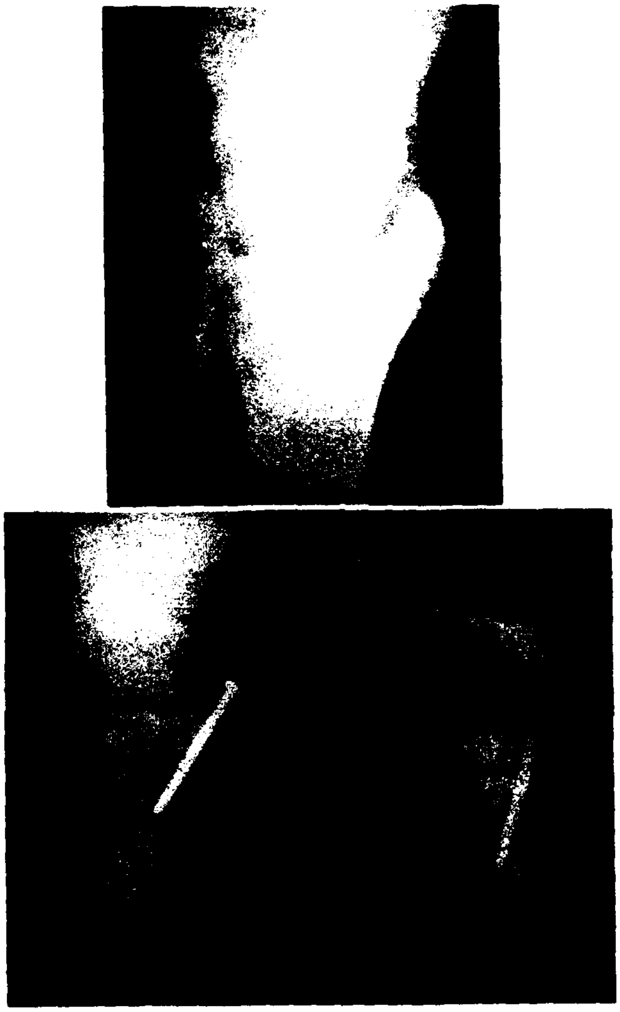

Figure 74.—Typical training injury: fracture of medial malleolus with nonunion after 4 months in cast. (Top) Anteroposterior roentgenogram of ankle area showing nonunion. (Bottom) Lateral and anteroposterior roentgenograms after fixation with bone graft and screw. The graft, of the small dowel type, was secured from the tibia higher up and was placed across the fracture site parallel to the screw. This patient returned to duty. (Breck, L. W.: Orthopedic Problems in Troop Training. [Unpublished data.])

the end of the war, the right-handed individual, who accidentally, on the last day of his furlough, shot off the third, fourth, and fifth toes of his left foot, was in the process of disappearing from the military records.

In spite of the restrictions imposed on the care of patients in military

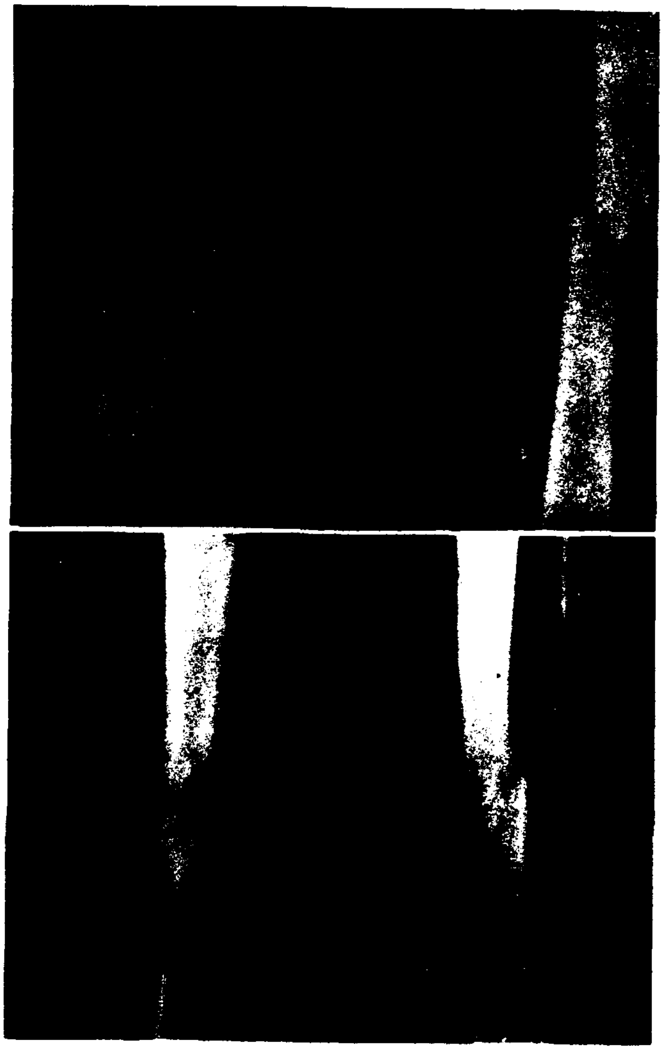

FIGURE 75.—Typical training injury: fractures of tibia and fibula. (Top) Lateral and anteroposterior roentgenograms after reduction of fractures and application of plaster. (Bottom) Same, 4 months after injury, showing solid bony union of tibia and probably union of fibula. This soldier had an excellent result. Closed reduction and immobilization in plaster proved the most satisfactory treatment for fracture of the tibia. Kirschner wire traction in balanced suspension was used only if it failed. (Breck, L. W.: Orthopedic Problems in Troop Training. [Unpublished data.])

situations, certain circumstances greatly simplified their management. One was their generally excellent physical status; most of them were strong young men, with no complicating conditions. Another was the absolute control which a medical officer could exercise over all his patients.

FIGURE 76.—Typical training injury: multiple severe fractures of superior and inferior pubic rami on left, fracture of ilium near sacroiliac joint on right, and separation of symphysis pubis. (Left) Anteroposterior roentgenogram immediately after injury. Note upward *displacement of pelvis on right* (Malgaigne's fracture). (Right) Same after reduction. This patient was able to return to duty. (Breck, L. W.: Orthopedic Problems in Troop Training. [Unpublished data.])

TYPES OF INJURIES

The patients with training injuries observed at Camp Maxey and reported by Captain Nickerson (*2*) are typical of those observed at other training camps throughout the country. They fell into two large groups administratively:

1. Patients with acute injuries sent into the hospital by direct admission from the emergency receiving room or by admission from the clinic.

2. Patients with conditions which required further treatment after initial treatment of their acute injuries and which frequently had to be managed surgically.

Conditions included in the first group reflected the hazards of the range and infiltration course, combat problems with live ammunition, night problems, and various simulated training situations. These injuries included:

1. Simple fractures sustained on the assault course; on the obstacle course; in vehicular accidents, many of them hit-and-run injuries; in sports and other recreations; and while on furlough.

2. Compound fractures (figs. 73–76) which included more severe degrees of the fractures just listed as well as less severe injuries sustained in the No. 3 category.

3. Injuries sustained from explosions and premature detonations during artillery practice, practice with landmines and grenades, faulty handling of bazookas, and similar situations. Carelessness accounted for some of these accidents, but with the laudable objective of training troops in simulated combat situations, it was impossible to avoid them all.

4. Gunshot wounds sustained chiefly with carbines or rifles, less often with machineguns. Their severity varied with the weapon responsible and the distance at which it was fired. A large number of these injuries, as just mentioned, were in the metatarsal area, between the first and third segments, and were self-inflicted.

The second category of injuries comprised:

1. Knee disabilities, including recurrent effusions, episodes of locking, osteochondritis dissecans, and similar conditions.

2. Fractures treated elsewhere, with insufficient union, delayed union, or nonunion. A certain number of soldiers who sustained these injuries had been assigned to Infantry Replacement Training Center units for instruction and training and had been returned to Camp Maxey for treatment.

3. Navicular fractures, which frequently required surgical treatment.

4. A miscellaneous group of conditions, many of them EPTI, including contractures; recurrent dislocations of the shoulder; scars that prevented proper function; osteochondromas; osteoarthritis of the acromioclavicular joint; osteochondritis dissecans of the elbow joint; and retained foreign bodies.

During 1944, most of the surgery done for training injuries at Camp Maxey was of the emergency type. In 1945, the ratio was reversed, for several reasons: Increasing numbers of patients were received from satellite hospitals, where they had had definitive treatment and had remained for varying periods of time. No transfers were included in this group unless it was thought that they would require further orthopedic surgery. Also, during 1945, a rather large number of men reappeared at Camp Maxey, suffering chiefly from fractures with nonunion or with insufficient union which had not held up under training at the Infantry Replacement Training Center.

A relatively large number of injuries were the result of skiing accidents, almost all of them incurred during training, but some of them sustained on weekends, when recreational skiing was permitted under military supervision. At Camp Grant, Ill., between 15 November 1942 and 15 May 1943, 101 of 183 fractures and associated injuries (about 54.6 percent) were directly attributable to such accidents (*5*). These injuries included 48 fractures of the lateral malleolus; 11 fractures of the shaft of the tibia; four diastases of the tibiofibular joint; one fracture of the shaft of the femur; 16 fractures of the bones of the foot; four fractures of the tibial tuberosity; four Colles' fractures; four avulsions of the shoulder; and one fracture each of the patella, the spine, the elbow, and the carpal scaphoid. None of the injuries could be attributed to failure of issue equipment.

INJURIES ON OBSTACLE COURSES

Obstacle courses at the various training camps in the United States were all constructed in much the same fashion (figs. 77–80). They were

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FIGURE 77.—View of obstacle courses. A. Camp Pickett, Va. B. Fort Jackson, S.C., 1943. C. Camp San Luis Obispo Range, Calif., 1943. D. Air Transport Command, Camp Carrabelle, Fla., 1942.

basically oval tracks, which contained hurdles, walls, ditches, and other impedimenta designed to develop the soldier's poise and self-confidence while he was overcoming physical obstacles. The two typical courses at Fort

FIGURE 77.—Continued.

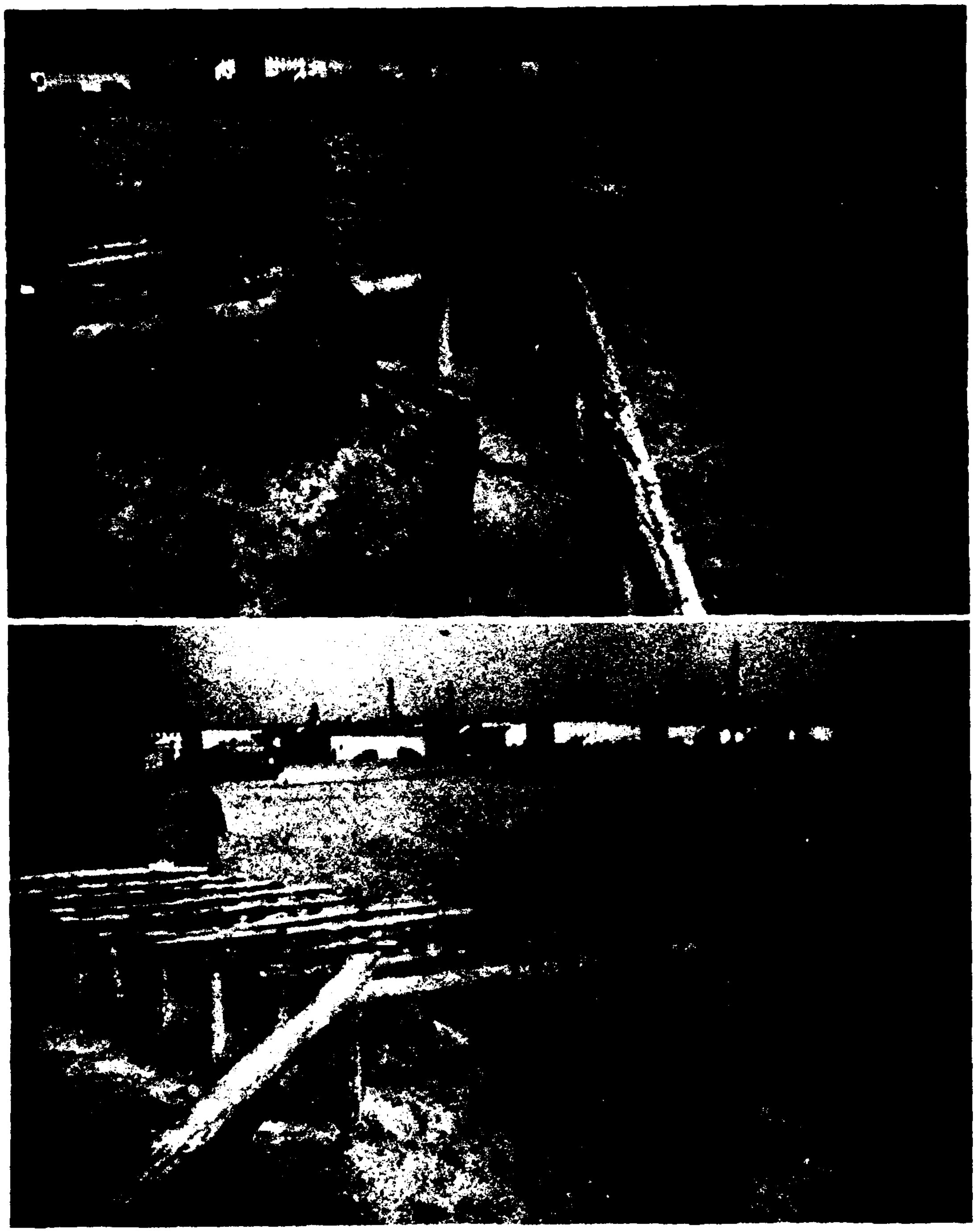

FIGURE 78.—Views of obstacle course, Camp Rucker, Ala., 1942–43.

Bragg were 163 yards long, and each contained 10 obstacles.

In a report from this training camp in June 1944, Major Sloane (*4*) reported that, over a period of a year, about 300,000 runs had been made over its two obstacle courses. They were associated with 38 injuries of

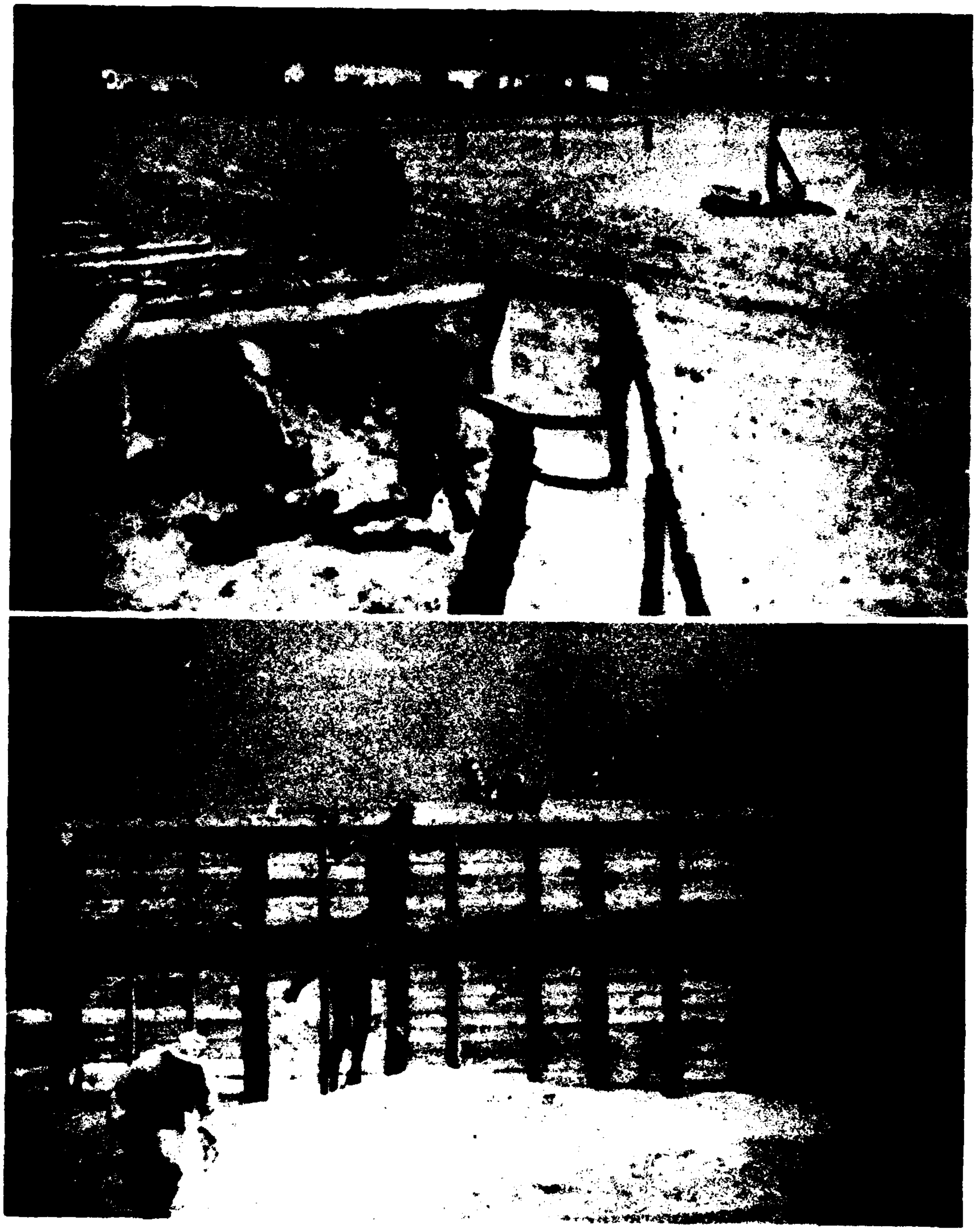

FIGURE 78.—Continued.

sufficient severity to require hospitalization, which lasted from 1 to 193 days, averaged 26 days, and accounted for a total manpower loss of 988 days. Analysis of these injuries produced the following data:

The man most susceptible to injury, and therefore requiring the closest

FIGURE 79.—Trainees negotiating water jump on obstacle course, Camp Barkeley, Tex.

supervision to prevent it, was untrained, uneducated, and approaching 40 years of age. About 19 percent of those injured were 35 years of age or older. Men who had been in the Army 6 months or less sustained 58 percent of the injuries; half of them had been in service a month or less. In the cases in which the weight was recorded, 30 percent of the injured weighed 175 pounds or more. One man, 6 feet 3 inches tall and weighing 232 pounds, was injured when a rung on a log ladder broke under his weight.

The injuries chiefly involved the ankles (17), with sprains the most frequent type. There were seven knee injuries; two mild injuries about the hip; one recurrent dislocation of the shoulder; one fracture of the greater tuberosity of the humerus; four low back sprains, one of them associated with a mild cerebral concussion; and another cerebral concussion, also mild. These 34 injuries accounted for 375 lost man-days, an average of 11 days for each injury.

In eight of these 34 cases, the injury was the result of a misstep. In the remaining 26 cases, 12 men were injured while straddling a wide ditch, nine by falling from a high wall or ladder, and five while going over low hurdles.

The four other injuries in this series, one of them bilateral, all were of the os calcis. They accounted for a total loss of 613 man-days, or an average of about 5 months each. The explanation of this notable discrepancy is quite simple: Normally, the small bones and ligaments of the feet, which are highly resilient, take up the physical shock of jumping and landing on

FIGURE 80.—Obstacle course activity at Quartermaster Replacement Training Center, Fort Warren, Wyo., 1942. Soldiers get the feel of leaving a ship hurriedly by the use of apparatus equipped with rope ladder along the side. Boats below them rock realistically and precariously.

the toes. When the mechanism misfires—that is, when it fails to function normally—the heels take the shock of the entire body weight and injury follows. The most serious injuries of the os calcis occurred on the tank trap, which required jumping from a height and straddling a ditch.

Considering the risks, the incidence of injuries on obstacle courses at Fort Bragg (and at other training camps) was low. The potential manpower loss, however, was very great. To reduce it, Major Sloane made the following recommendations:

1. A commissioned officer should always be present during activities on the obstacle course, to supervise them and to keep misfits and ill men from undertaking them.

2. Signs should be posted on the course to warn the men first to walk through it to observe the obstacles, then to run through it slowly, and finally to run through it as fast as possible.

3. The men should clearly understand exactly what they are supposed

to do. A number of the injuries in this series occurred because the trainees attempted to jump across a ditch that they were supposed to jump into and then climb out of.

4. All obstacles should be built strong enough to withstand rough usage and should be checked periodically to keep them in repair.

5. A record should be kept of the site of all accidents. If an unusual number should occur at any one point, that obstacle should be modified. At Fort Bragg, injuries of the os calcis ceased when a wall was lowered and a ditch narrowed.

THERAPEUTIC CONSIDERATIONS

Fractures were the injuries most frequently incurred during training, and most of them involved the hands, wrists, feet, and ankles. Since they differed in few respects from fractures and injuries incurred in other circumstances, they are discussed under the appropriate general headings in the section on regional fractures in this volume (p. 489). A few words, however, should be said here about their management.

Regional hospitals on training posts which received patients from satellite hospitals naturally had a high proportion of open reductions; patients with no problems seldom reached these hospitals. In the Zone of Interior, as overseas, the use of delayed primary wound closure in compound fractures was one of the great advances of World War II, as was proved again by its application in training injuries.

Hand injuries (which are discussed in detail in the volume in this historical series devoted to them (*6*)) were usually handled jointly by the orthopedic and general surgery sections. They were frequently caused by hand grenades, and surprisingly often, they took a special form: The thumb either was blown off entirely or was partly separated from the hand, with accompanying damage to the fingers. In one bizarre injury, reported by Major Breck from Camp Swift (*1*), the force of a grenade explosion blew two fingers from one man's hand into another man's forearm. The man holding the grenade was killed. It was difficult at first to identify the source of the small bone fragments seen on the roentgenogram in the other man's forearm (fig. 81).

The results of hand surgery, considering the severity of the injuries, were often surprisingly good.

Fractures of the carpal scaphoid (p. 575) were the nuisance of all training areas. They were usually treated efficiently because of the lucid directives that had been issued concerning them. Also, many articles in the medical literature of the early war years directed attention to their possible occurrence and to the importance of their prompt and prolonged immobilization. Even when they were well treated, however, fractures of this one small bone delayed thousands of trainees from participation in combat functions over long periods of time.

FIGURE 81.—Lateral roentgenogram of forearm showing extraneous bone fragments from (two) fingers of another soldier who was holding a hand grenade when it exploded and killed him. (Breck, L. W.: Orthopedic Problems in Troop Training. [Unpublished data.])

Fractures of the long bones, particularly of the femur, often made it impossible for the patient to continue in training. The best results were obtained with skeletal traction, which seemed to reduce the residual stiffness in adjacent joints.

There was no known instance of tetanus at any of the training camps, and no recorded reaction from the tetanus toxoid given in stimulating doses to all trainees with compound fractures. Gas gangrene was practically unknown, and postoperative infections were extremely uncommon, one reason being the prompt care which the injured almost invariably received.

PHYSICAL THERAPY AND RECONDITIONING

Physical therapy and reconditioning had an important place in the management of training injuries. The employment of quadriceps exercises, for instance, often made the difference between success and failure in knee injuries. A decided change in the mental attitude of trainees, as well as an improvement in their physical status, was evident after the reconditioning program was put into effect (p. 470). The number of those who could be returned to full duty showed a prompt and material increase. This was not, however, a program to be applied universally. Selection of patients for it was necessary. Most patients with low back pain were not benefited by it,

to use one example, and their poor performance and persistent complaints tended to demoralize other patients and disrupt the program.

The morale of orthopedic patients under treatment for long periods of time is often a problem in civilian practice and was a serious problem in the training program. With the improvement that occurred in his physical status in the course of the reconditioning program, there was usually a corresponding improvement in the trainee's morale, and another serious difficulty in the training program was thus eliminated.

SPECIAL CASES

Zenker's degeneration of voluntary muscle.—While most training injuries fell into regular patterns, occasional unusual and even bizarre injuries were encountered. One has already been mentioned, the grenade explosion that blew a fragment of one man's fingers into another man's forearm. The following case history is also unusual (*7*):

Case 1.—In the course of mass athletics, a soldier was accidentally kicked in the left popliteal fossa by the heel of his partner's shoe. He had an immediate sensation of charleyhorse, and when he tried to work it off by running, he had to stop because of a sensation that "something had ripped" behind the left knee. Next day he could not straighten the knee completely. It was painful at rest, and flexion was extremely painful.

Two weeks later, the patient noticed a lump behind the left knee, with a widespread greenish discoloration of the popliteal fossa 6 inches above and 6 inches below it. Over the next 3 weeks, the discoloration disappeared, but the lump persisted and was painful after long marches.

Five weeks after the original injury, while he was making a run for a fly in a baseball game, the patient again felt "something rip" in the popliteal fossa and experienced the original symptoms and signs, though less intensely and for a briefer time. The popliteal fossa was slightly swollen and painful, but there was no ecchymosis. Improvement was prompt, and again he experienced symptoms only after long marches.

This man completed his basic training, but during a routine examination in the staging area, the mass in the left popliteal fossa was found and he was admitted to Halloran General Hospital, Staten Island, N.Y.

The mass was 6 by 2.5 centimeters, pear-shaped, nontender, firm, and fixed in its lower portion but slightly movable above. It extended upward from the left popliteal fossa just lateral to the medial hamstring tendon. After it was removed at operation, it was reported as Zenker's degeneration of voluntary muscle.

The mechanism of injury in this case was probably as follows: The plantaris was unusually well developed and thus was exposed above the origin of the lateral head of the gastrocnemius. It could, therefore, be torn from its origin along the linea aspera by the blow sustained. At the same time, it was probably deprived of its blood supply from the genicular arteries, and the result was a degenerative reaction of the muscle belly.

Herniation of muscles of leg.—Herniation of the muscles of the lower leg, an infrequently reported condition (*8*), was sometimes a training injury and sometimes had been present before induction, as shown by the

duration of symptoms, from 1 week to 4 years, in the 31 cases reported by Maj. Lewis N. Cozen, MC (*9*). These cases were all observed over a 1-year period. This fact, combined with the 38 hernias observed in 21 patients in 1,800 admissions to the orthopedic clinic at the Marine Corps Base at San Diego, Calif. (*8*), suggests that this condition was probably far more frequent than it was supposed to be.

In Major Cozen's case, the peroneal muscles were herniated three times, the extensor digitorum longus in one case, and the tibialis anticus in all of the others. Six patients had no symptoms; in all of the other cases, pain was experienced at the site of the herniation after marches.

The application of an elastic bandage was the only treatment used in 11 patients, who complained of only mild pain at the site of the fascial defect. The other 14 patients with symptoms, all of whom complained of severe pain, were operated on, 13 of them by a new technique: The hole in the fascia, instead of being closed (an attempt which failed in the first case handled surgically), was enlarged by a cruciate incision so that the muscle would bulge through as a large mass instead of crowding through the original small opening. All the patients were relieved over the period of observation (up to 4 months) except one, who proved to be psychoneurotic and who should not have been operated on.

Achillodynia.—Painful irritation of the Achilles tendon and of the small bursae surrounding it near its insertion into the calcaneus was observed fairly frequently in recruits (*10*). It was caused by the transition from low civilian shoes to the regulation GI shoes and was compounded by the increased activity, particularly marching, required in the Army. The irritation apparently was caused by the constant pressure of the counter of the high shoes on the insertion of the tendon, which caused extreme pain and tenderness above the heel with every step of the affected foot. Examination might be negative except for local tenderness or might reveal reddening and swelling of the involved area. Crepitation was sometimes present on movement of the foot.

At one hospital, an effective method of treatment was strapping the foot and leg in such a manner as to relax the Achilles tendon (fig. 82):

> Tincture of benzoin was applied to the sole of the foot and the shaven back of the leg, and the adhesive was applied with the leg perpendicular, the foot in moderate extension, the heel 1 inch off the ground, and the ball touching the ground. Three long parallel strips of adhesive ran from the metatarsal arch over the heel to the mid calf. They were anchored by two short crosspieces over the ball of the foot and the heel and by two other crosspieces above the ankle and the calf. The patient was instructed to step gingerly for several minutes, to allow the tape to stretch slightly. He was also instructed to lace his shoes only to the third eyelet from the top, to relieve some of the causative pressure.

Complete relief was usually accomplished after the strapping had been maintained for 3 or 4 days. Restrapping was necessary in recalcitrant cases.

All the cases treated in this manner were acute and new, and all were

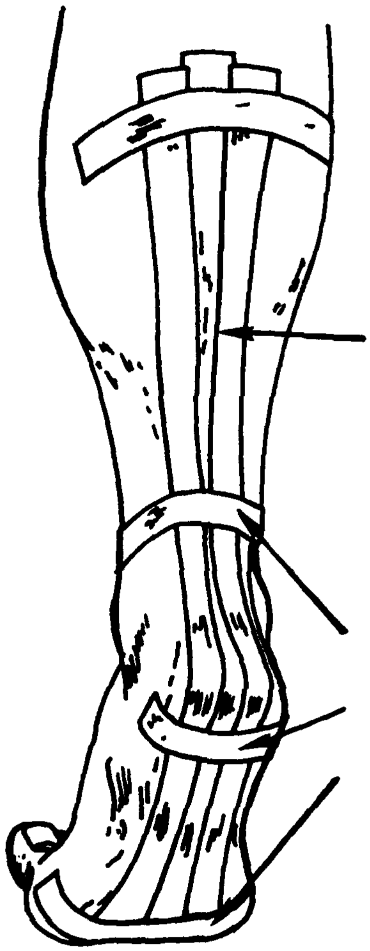

FIGURE 82.—Application of adhesive tape for relief of achillodynia. (Bull. U.S. Army M. Dept. 77: 21–22, June 1944.)

handled before trophic changes developed. Hospitalization was not required in any instance, and the man, as a rule, was able to carry on full field duties.

Aseptic tenosynovitis.—A more advanced stage of this condition, in the form of aseptic tenosynovitis, was observed in a number of trainees at Camp Maxey (*2*). In the majority of cases, the extensors of the toes and foot were also involved. Some recurrences involved additional tendons. In a few cases, both the initial attacks and the recurrent episodes were severe, and in one instance, marked thickening of the tendon sheath of the tibialis anticus had to be managed by surgery. As a rule, there was good response to rest and physical therapy. The explanation of most of these cases was irritation from the GI shoe.

Massive necrosis of components of anterolateral compartment of leg.—An unusual instance of massive necrosis of the components of the anterolateral compartment of the left leg, observed at Camp Maxey (*2*), began with sudden onset of pain and swelling after a long march. The dorsalis pedis pulsation soon disappeared. The skin was shiny and tight. When areas of apparent fluctuation developed, a general surgeon twice made exploratory incisions but found no evidence of exudation. Eventually, all the tissues in the area sloughed out. Closure was accomplished in two stages, over a period of 4 weeks, under penicillin protection. Complete loss of dorsiflexion and eversion was partly overcome by transfer of the tibialis posticus and peroneus longus tendons to the lateral cuneiform. They were linked to each other in the form of a sling, and a tunnel was prepared for them in this bone. Four months after operation the patient had most of the power from the peroneus longus, but very little from the tibialis posticus.

Trauma to lumbodorsal fascia.—The following case, reported by Capt. (later Maj.) Morgan Sargent, MC, illustrates an unusual cause for persistent back pain which developed in the course of training:

Case 2.—A 24-year-old soldier, while squatting on the ground, lifted a .50-caliber machinegun above his head to place it beneath the wing of a fighter plane. He lost his balance but maintained his grip on the gun, the heavy weight of which dragged him backward and to the side. At the same time, he felt a tearing pain in the right lumbar region. The pain was so severe that he straightened up with great difficulty. Roentgenograms were negative.

He spent most of the next 2 weeks in bed, without relief from strapping, massage, baking, or injection of air beneath the lumbar fascia. Then he began to improve, was able to do light work, and eventually became an aerial gunner and completed an overseas tour of combat duty.

For the next 18 months, however, he continued to have a localized area of tenderness in the right lumbar region, which became painful after bending forward, attempts at lifting, and prolonged standing or sitting. Surgical consultation was requested while he was hospitalized for operational fatigue. Examination showed an area of tenderness, about 4 centimeters in diameter, over the right sacrospinalis muscle, at the level of the third lumbar vertebra. Even slight forward bending was painful. When the patient stood in a cross light, a small but definite bulge was apparent over the painful area; the bulge was exaggerated when he coughed or started to bend forward.

Infrared therapy and massage gave no relief, but on three separate occasions, 5 and 10 days apart, complete relief was secured, and full, nonpainful motion of the back was possible, after infiltration of the tender area with 5 cubic centimeters of 1-percent Novocain (procaine hydrochloride) down to, and including, the posterior layer of the lumbodorsal fascia.

Exploration under local anesthesia was carried out through a transverse incision directly over the bulge, down to the fascia, in which there was clearly evident an elliptical split, about 1 by 4 centimeters. The gap was thinly bridged with loose areolar tissue. The underlying sacrospinalis muscle was normal in appearance and to palpation, and the fascia, except for the slit, seemed strong and otherwise normal. The slit was closed with interrupted cotton sutures, care being taken to avoid strain on the strands of fascia immediately adjoining the margins of the gap.

Early activity was encouraged. Within 3 weeks, the patient had full motion, without pain or local tenderness. At the end of 3 months of observation, he was very active, was participating vigorously in athletics, and had no pain or discomfort.

As this case history shows, the possibility of a traumatic longitudinal slit in the posterior layer of the lumbodorsal fascia should be included in the differential diagnosis of persistent localized back pain after trauma.

Spondylolisthesis aggravated by service.—The following case is another instance of relief of service-connected back pain and of rehabilitation of a valuable soldier by proper selection and competent surgery:

Case 3.—A 37-year-old soldier, with 17 years of service, was admitted to Halloran General Hospital because of disabling pain in the lower back and right leg. The pain in the back had begun 4 years earlier, following a fall during a jujitsu contest, and had gradually increased in severity. The pain in the leg was of 6 months' duration. There were definite symptoms and signs referable to the right fourth nerve root. Roentgenologic examination showed spondylolisthesis between the fourth and fifth lumbar vertebrae.

As this man had highly specialized skills and was of great value to the Army, operation was regarded as justified, especially since the spondylolisthesis, although undoubtedly congenital, had clearly been aggravated by military service. Right unilateral laminectomy of the fourth lumbar vertebra was performed when scar tissue and compression of the nerve root were revealed at exploration. After the compression was relieved, spinal fusion was carried out with the use of a large tibial graft and multiple bone chips over the left lamina. Additional fixation was obtained by a Wilson plate attached to the spinous processes at the third, fourth, and fifth lumbar vertebrae and the first sacral vertebra. The patient returned to full infantry duty at the end of 9 months, and 2 months later, was carrying out his assignments with no pain or disability.

Phantom bone.—Acute spontaneous absorption of bone (phantom bone) is an extremely unusual condition. When the following patient (fig. 83) (*11*) was encountered,[2] only two similar cases had been reported, one of the humerus (*12, 13*) and the other of the facial bones (*14*). Maj. Hira E. Branch, MC, made the diagnosis because he recollected having heard the report of a similar case some years earlier:

Case 4.—This 20-year-old Negro was seen in Harmon General Hospital, Longview, Tex., on 3 June 1944. Early in May, during ordinary rifle drill at a nearby camp, he had rolled over on the ground, pressing his rifle against his left shoulder. He had some immediate pain and discomfort in this area and gradually became unable to raise his arm above his head. He was admitted from a station hospital with the diagnosis of bone tumor; by this time, his pain had disappeared.

Examination revealed a depression in the area where the left clavicle should have been and mild crepitation where the superior border of the scapula should have been. The head of the humerus on the right was slightly higher than the head on the left. Arm motion was limited but was not painful.

Roentgenologic examination on 18 May 1944 had revealed absence of the outer two-thirds of the left clavicle and only fragments of the superior border of the scapula.

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[2] The patient with the fracture of the humerus was followed for many years, and when he died, at the age of 70, in the Boston Lunatic Hospital, the arm was dissected at the Harvard Medical Museum. The history differed from that of Major Branch's patient in that the absorptive process originated in a fracture (sustained while holding "under disadvantages, an enraged cow by the horns") which was followed by a second, and then by a third, fracture in the same area. An editorial in the *Journal of the American Medical Association* in 1964, "The Case of the Disappearing Bones," brings together 49 instances of this anomaly from 12 different countries, all reported since 1954 (*14*). The current (1968) theory of etiology seems to be that osteolysis is due to hyperemia and that osteogenesis, in contrast, is promoted by a decrease in local circulation. The theory seems reasonable but remains to be proved.

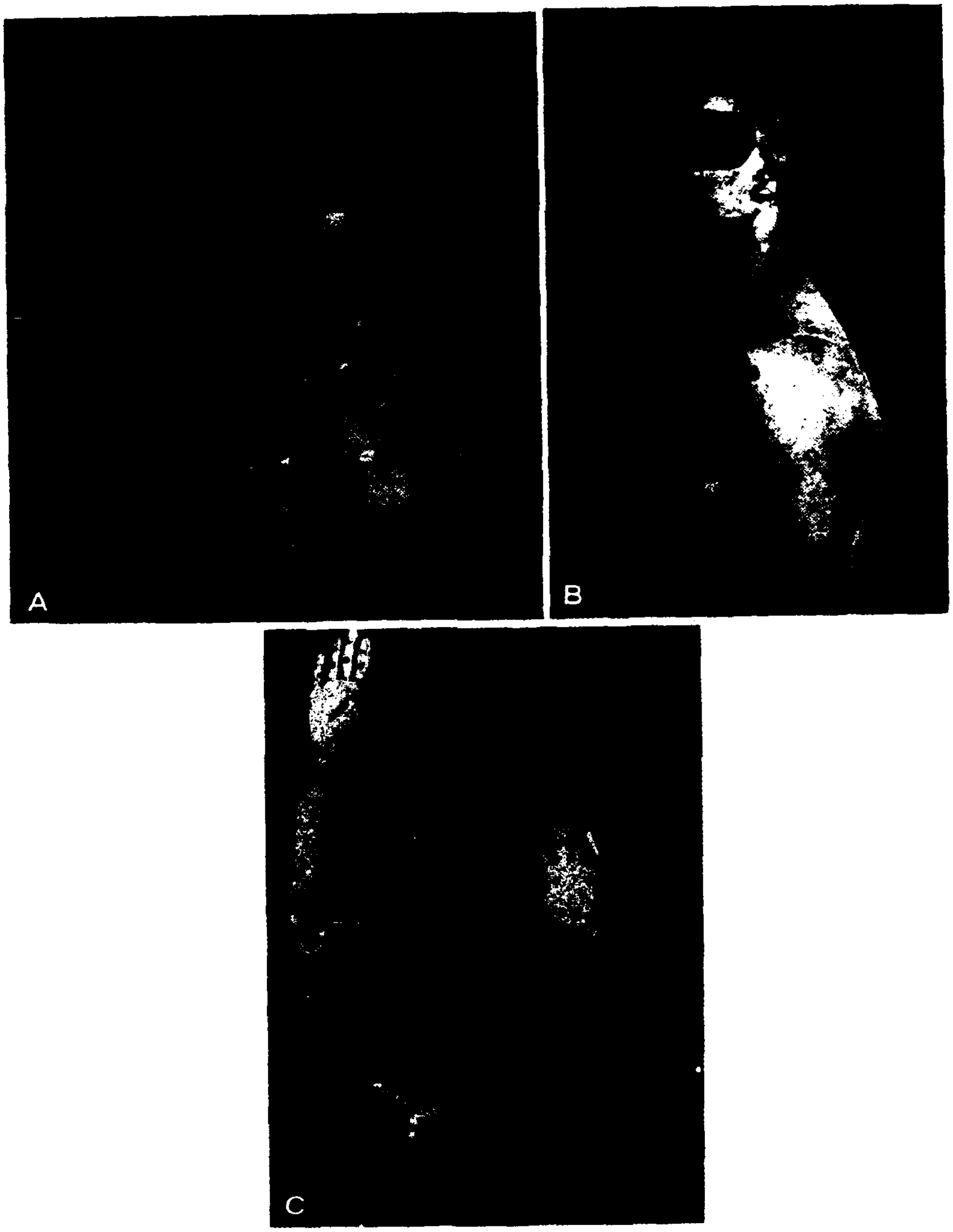

FIGURE 83.—Acute spontaneous absorption of bone. A. Otherwise well-developed soldier with depression in area where outer two-thirds of left clavicle and acromion process would normally be. Scar is from biopsy. B. Lateral view showing depression in area where superior border of left scapula would normally be. C. Loss of abduction of left shoulder due to absence of acromion process and clavicle.

Examination on June 6 revealed absence of the clavicle, the acromion process, and the superior border of the scapula, and a "disappearing" process in the neck of the scapula. Examination on 11 September showed progressive absorption of the clavicle and the upper portion of the scapula.

FIGURE 83.—Continued. D Anteroposterior roentgenogram taken on 18 May 1944 and showing absence of outer two-thirds of left clavicle. Note remaining fragments of superior border of scapula. E. Same, taken on 6 June 1944, showing absence of left clavicle, acromion process, and superior border of scapula. Note that neck of scapula is disappearing. F. Same, taken on 11 September 1944, showing progressive absorption of clavicle and upper portion of scapula.

A battery of laboratory tests, including roentgenologic examination of all the patient's other bones, were negative.

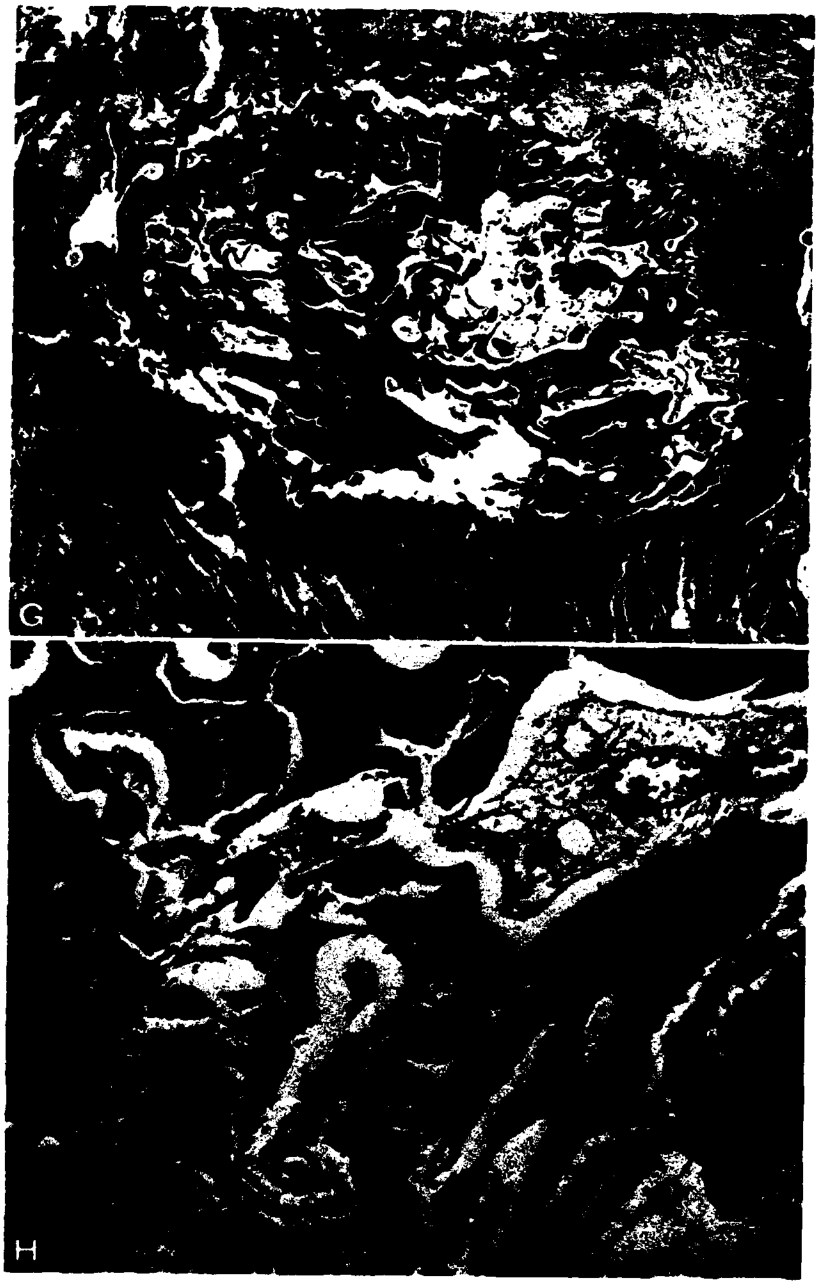

FIGURE 83.—Continued. G. Photomicrograph (× 16) of section through area in left shoulder where medulla of clavicle should have been. (U.S. Army negative 89408). H. Photomicrograph (× 104) of section through actual bone of scapula at edge of degenerative process. (U.S. Army negative 89407). (Branch, H. E.: J. Bone & Joint Surg. 27: 706–710, October 1945.)

Exploration on 14 June 1944, on the diagnosis of phantom clavicle and scapula, revealed only fibrous tissue where the clavicle, the superior border of the scapula, and the acromion process should have been. Histologic examination of excised specimens revealed no evidence of vascular, inflammatory, or neoplastic disease.

After this case had been reported, it was found that a somewhat similar case had been observed at Thomas M. England General Hospital, Atlantic City, N.J., in October 1943 (*15*).

Case 5.—This patient was received with a spontaneous fracture of the neck of the left femur. The fracture had been incurred 6 months earlier and had been treated by internal fixation with a Smith-Petersen nail and a tibial bone graft. Roentgenograms at England General Hospital revealed no union and 75-percent absorption of the femoral neck. The bone graft was removed and the femoral neck and fracture area curetted. A McMurray osteotomy was performed, and early bony union was evident at the end of a 9-week period of observation. Examination of the specimen excised at operation showed no malignancy and no other explanation for the absorptive process.

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Part III

RETURNED CASUALTIES

CHAPTER VII

Status of Orthopedic Casualties Returned to the Zone of Interior

George K. Carpenter, M.D., Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

GENERAL CONSIDERATIONS

Clinical Policies

Delayed primary wound closure wa never practiced universally in World War I, but its limited use gave excellent results in the last months of combat (p. 331). It is hard to explain, therefore, except by the rather general ignorance of the World War I experience, why it was not used in the U.S. Army in World War II until the fall of 1943.

The United States experience with the closed plaster (Orr-Trueta) technique[1] had been reasonably good in civilian practice, and the method was simply carried over into military surgery. Theoretically, this was a sound method. In practice, when it was applied in the North African theater, it proved unworkable (*2*). Casualties frequently were febrile when they were received in general hospitals. If the casts had been split or bivalved, as theater regulations required, the plaster was often disintegrating and correspondingly ineffective. Even when fractures had been reduced adequately in forward hospitals, position was likely to be lost in transit over long distances and rough roads, and a second reduction was necessary at the general hospital. Blister formation, excoriations of the skin, and pressure sores were frequent. If pins had been used, they were often broken, and infection about them followed and sometimes went on to osteomyelitis. The casts were described correctly as "sad, smelly sights." Finally, wounds treated by this method healed slowly and poorly, and the thick scar tissue that formed made subsequent bone grafting, nerve suture, and other repair operations difficult and sometimes impossible.

Results such as these clearly could not be accepted, and in the spring of 1943, modifications of the technique were introduced into hospitals in North Africa. Casts, which had originally been left in place for 4 to 6

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[1] The closed plaster technique was devised by H. Winnett Orr for the treatment of osteomyelitis in civilian practice. Trueta adapted the method to the treatment of gunshot wounds in the Spanish Civil War (*1*).

weeks, were removed at the end of 15 days, the wounds were inspected, and such fracture management as was indicated was carried out. By the fall of 1943, delayed primary closure of clinically clean soft tissue wounds began to be practiced by isolated surgeons, preferably 4 to 7 days after debridement, which had become far more extensive with the growing realization that prevention of infection rather than management of fractures was the first concern in forward hospitals. The new policy was enthusiastically encouraged by Col. Edward D. Churchill, MC, Consultant in Surgery to the theater surgeon, and by the spring of 1944, delayed primary wound closure was generally used not only for wounds of soft tissues but for compound fractures also (*3*). The new program was extremely successful, fundamentally as the result of good surgery, but it should also be remembered that it was put into operation just at the time that penicillin became generally available and the establishment of a theater blood bank made liberal transfusions practical.

The evolution of the overseas policy just summarized was reflected in the local and general status of patients received in hospitals in the Zone of Interior and dictated their management.

Administrative Policies

An appreciation of the status of casualties returned to the Zone of Interior in World War II requires some background knowledge of the policies that governed hospitalization and evacuation overseas. This information is set forth in detail in the volume in this historical series dealing with those subjects in the Zone of Interior (*4*). The reader is referred particularly to chapter XIX, which deals with estimated and actual requirements for evacuation from theaters of operations, and chapter XX, which deals with the development of procedures for evacuation from theaters overseas to the Zone of Interior.

Among the relevant subjects discussed in these two chapters are the following:

1. The use of hospital ships, built and operated for the Army by the Navy, and the development of air transport. These measures reduced the evacuation of casualties by ship transport from 92.8 percent in 1943 to 61.4 percent in 1944.

2. Classification of casualties to be evacuated into three groups: (a) mental; (b) troop class, consisting of patients who needed only minimal attention and could care for themselves, even in emergencies; and (c) hospital patients. The hospital group was divided into two subgroups; namely, bed (litter) patients and ambulant patients. The latter subgroup required medical care and attention but were not confined to bed at all times.

3. The system of overseas reports, which provided for Zone of Interior authorities (a) the number of patients in each of these groups evacuated in each transport, plane, or hospital ship, and (b) the number in each such group awaiting transportation. With this information—which originally did not always arrive or was not always correctly categorized—Zone of Interior needs for hospital beds could be calculated and provided for.

4. Provision for medical personnel to care for casualties during transportation.

5. Provision for medical supplies during transportation.

6. Procedures for air evacuation, including the establishment of priorities based on needs.

7. Plans for transfer of casualties from ports and airfields in the Zone of Interior to hospitals for definitive treatment. These plans included debarkation, movement to nearby debarkation hospitals, reception and triage at these hospitals, and preparation for further transportation.

FLOW OF RETURNED CASUALTIES

During the first 6 months of 1944, the average number of casualties received in the Zone of Interior from overseas was about 9,000 per month (*5*). After D-day, the numbers rose steadily; 30,000 were received in December 1944 and 35,000 in February 1945. In March 1945, the rate rose to 1,200 per day. Meantime, the bed capacity of Army general hospitals and convalescent hospitals in the Zone of Interior was increased by 70,000.

About 40 percent of the evacuees received in 1944 came from the European theater, about 25 percent from the Mediterranean theater, 18 percent from the Southwest Pacific, and 15 percent from the Pacific Ocean Areas. During the last quarter of 1944, the European theater accounted for more than half of all returned casualties, who represented the sick and wounded hospitalized overseas on an average of 2 to 3 months earlier.

In 1944, nearly a fifth of the evacuees reached the Zone of Interior by plane, the peak of air transport being attained during the third quarter of the year. The decline in the last quarter was chiefly explained by adverse weather conditions over the Atlantic during the fall and winter. The number evacuated by air from the Pacific steadily increased during 1944. About 20 percent of the casualties from the Southwest Pacific Area and nearly a third from the Pacific Ocean Areas arrived in the United States by air during the last quarter of 1944.

Battle casualties accounted for 12 to 15 percent of evacuees in the first half of 1944, 35 percent in the second half, and 60 percent during the last 3 months of the year. This increase necessitated the increase in hospital beds just mentioned, because hospitalization for wounds generally was longer than for medical conditions. For 1944 as a whole, about 40 percent of the evacuees from both the European and the Mediterranean theaters were battle casualties, as contrasted with 6 percent from the Southwest Pacific Area and 11 percent from the Pacific Ocean Areas.

Analysis of the casualties evacuated for trauma in 1944 showed that wounds and compound fractures each accounted for about 30 percent of the total number. During the last quarter of the year, when the full impact of battle casualties began to be felt, wounds increased to 35 percent and compound fractures to 45 percent of all evacuations for trauma. For the year as a whole, simple fractures accounted for 10 percent, and loss of parts of the body for 5 percent, of such evacuations. The distribution of evacua-

tions for trauma was 45 percent for the lower extremities; 27 percent for the upper extremities; 12.5 percent for the head, face, and neck; 5 percent each for the abdomen and the thorax; and 5.5 percent for other regions.

The figures just cited have been stated in detail to show the dominance of wounds of the extremities, which accounted for well over half of all casualties evacuated to the Zone of Interior. It was the general experience of Zone of Interior hospitals that, while the proportion of orthopedic casualties varied from convoy to convoy, it was always greater than that of any other special type of injury.

In addition to the evacuations to the Zone of Interior for orthopedic trauma, diseases of the musculoskeletal system accounted for about 5 percent of all evacuations. Evacuees with arthritis comprised almost 5 percent of evacuations for disease.

ROUTINE IN DEBARKATION HOSPITALS

Debarkation hospitals [2] carried heavy responsibilities. Their function was to transfer all casualties who did not need to be held for treatment—that is, who were transportable—to other hospitals within 72 hours of their reception. The deadline was necessary to provide for the constant stream of new returning casualties. To meet it required examination of each patient individually, dressing of his wound(s), changes of cast as indicated, medication as indicated, and other medical attention. It also involved voluminous paperwork, to provide records for the debarkation hospital itself; reports to the Pentagon on patients received; orders for transfers to other hospitals; arrangements for transportation; provision of uniforms; and provision for partial pay due. The paper workload was reduced somewhat as the war progressed, but it remained heavy and time-consuming

[2] Since much of the material in this chapter is derived from the experience of Halloran General Hospital, Staten Island, N.Y., and was provided by Dr. (formerly Lt. Col., MC) George K. Carpenter, Chief of the Orthopedic Section from November 1942 to August 1945, a statement of certain background facts may be useful. This hospital, which was officially opened on 10 November 1942 (and was receiving casualties from overseas within the week), served (1) as a debarkation hospital, from which returned casualties were evacuated to other hospitals for definitive care; (2) as a hospital for definitive care; and (3) as a specialized center for neurology, neurosurgery, and orthopedic surgery. It was officially classed as a 5,358-bed hospital. When the need for a hospital in this location (the Second Service Command, comprising New York, New Jersey, and Delaware) arose in 1942, the buildings had just been completed by the State of New York for use as a school and hospital for mentally defective children. The buildings could be adapted readily to military hospital use, and before the war ended, the original permanent structures were supplemented by several cantonment-type wooden buildings.

Personnel of the orthopedic section, in addition to Colonel Carpenter, consisted of Capt. Harry Zubkoff, MAC, executive officer; Lt. (later Maj.) Robert T. Rosenfeld, MC, and Capt. (later Maj.) Karl F. Mech, MC, who became expert in this specialty during their wartime service; and a number of other officers who also were trained on the service because there were no trained personnel to assign to it. It was an extremely capable orthopedic staff, which worked remarkably well together and with the rest of the hospital staff, one reason being the competence and cooperation of the Commanding Officer of the hospital, Brig. Gen. Ralph G. DeVoe. In April 1945, the neurosurgical staff from Walter Reed General Hospital, Washington, D.C., was moved to Halloran General Hospital, and Capt. Hugo V. Rizzoli, MC, participated in the management of combined orthopedic-neurosurgical injuries.

During the operation of the hospital, there were five deaths on the orthopedic service, most of them apparently so classified for administrative purposes. The only patient from overseas was in no condition to tolerate amputation on his arrival, and in spite of intensive preparation was never able to tolerate it.

until the end. As time passed, there was a rapid decrease in the time needed to remove casualties from ships to receiving hospitals. The port of Charleston, S.C., cut the time for 600-patient loads from 5 hours early in 1944 to 2 hours by the end of the year and to 1 hour in 1945. The port of Boston, Mass., on one occasion in 1945, moved 1,958 casualties, including 287 litter patients, from the transport to nearby hospital trains in 2 hours and 20 minutes.

The theory was that hospital authorities in the United States would be notified, as far in advance as possible, of the contemplated arrival of casualties from overseas and of their approximate number and categorization. This notification was occasionally received by the hospitals concerned as far in advance as 48 hours. More often, it arrived only 6 or 8 hours before the casualties, and sometimes, notification and convoy arrived almost simultaneously. For some odd reason, 2100 was the favorite hour of arrival at Halloran General Hospital.

The original policy, when casualties were received in debarkation hospitals, was to process them through the reception center before admitting them to the wards. In May 1943, The Surgeon General directed that casualties from overseas be admitted directly to the wards, without delay for paperwork, so that food, rest, and such urgent treatment as they might need could be provided for them immediately. At the request of the Commanding General, Second Service Command, Halloran General Hospital was permitted to continue the extremely efficient system it had developed.

This hospital had organized a receiving ward large enough to accommodate several hundred patients at a time; a messhall to feed them immediately on their arrival; space for immediate examination and for emergency medical and surgical care; bathing facilities; storage space for their clothing; provision of hospital clothing; and space for administrative processing, including space for the batteries of typists brought in to handle paperwork. When this system was fully developed, the average stay of casualties in the reception building before admission to the wards was 61 minutes.

Originally, all returned casualties were carded simply for the record as they passed through the hospital receiving office (*4*). Later, they were coded and given E numbers by a system developed by the Medical Regulating Officer in the Surgeon General's Office. Originally, they were reported in certain categories such as psychiatric, surgical, and orthopedic. Later, a system was set up by which (1) returned casualties were reported to Washington within 12 to 24 hours after they were received and (2) instructions concerning their disposition were received, in turn, within another 12 to 24 hours.

If no beds were presently available to the hospital to which a casualty was to be assigned for treatment of his special type of injury, he was held at Halloran General Hospital until bedspace became available. This plan created certain internal problems. If the patient could be moved out within 3 or 4 days after his arrival, there were no difficulties. If he was kept beyond that time, he was caught up in the administrative routine of the

hospital and had to be held longer. On certain occasions, for this reason, the hospital had to carry and care for large numbers of patients who could not be moved until further instructions for their disposition were received from the Medical Regulating Officer in Washington. Halloran General Hospital, like other general hospitals, while it was caring for these returned casualties had its assignment of other patients for whom it had to supply definitive care.

Triage

As soon as returned casualties had been processed administratively and had been fed and otherwise cared for, the important business of triage was begun. That is, the casualties had to be sorted out, to determine which ones could be transported safely to other hospitals and which had to be retained at Halloran General Hospital for definitive care or for various other reasons. Not too much time could be spent on this task, for there was never any certainty when the bedspace occupied by these casualties would be needed for other convoys. Whenever a convoy arrived, therefore, the entire hospital went into action. Dermatologists, internists, neuropsychiatrists, otolaryngologists, urologists, dental officers, and others, all of whom had been trained for such emergencies, participated in the task. As a rule, the only personnel not engaged in the direct care of the patients were X-ray personnel, who were busy taking roentgenograms, and laboratory personnel, who were busy running tests and typing blood.

At first, triage was rather crude. A man with a cast was listed automatically as an orthopedic casualty, though sometimes he had other and more serious wounds. A man on a litter went to a certain building and an ambulatory patient went to another. The principal decision was whether or not the individual in question was fit to be moved out of the hospital. Once he was tagged as nontransportable, he could not be moved until the medical officer who had so classified him changed his tag.

Some classifications were simple: A casualty with a satisfactory cast on a fracture of the radius and ulna, who lived in New York, N.Y., or in some township close by, presented no problems. He was ready for immediate evacuation because his condition was good, he needed no preparation for the journey, and the travel would entail no strain. In contrast was a casualty with compound fractures of the tibia and fibula, whose cast was foul-smelling and beginning to soften because it had been intended for a 3-week trip which had lasted, instead, for 6 weeks; seemed exhausted by his journey from overseas; who looked anemic and ill; and who lived in Minneapolis, Minn. Clearly, a man in this condition would be improved by a change of cast, blood transfusions and other supplemental therapy, and a few days of rest. The decision to hold him, however, was not so simple. It had to be made in the light of casualties to be expected shortly, whose need for beds might be even greater than his own. A patient with an infection was in one category; as a rule, it would be safe—though not always desirable—to remove him at once to the hospital to which he was assigned for definitive care. On the other hand, a patient with any indication of bleeding, or any history of bleeding, must

be held until all risk of hemorrhage was positively past, no matter how long that might be (p. 321).

Triage soon became a highly efficient performance at Halloran General Hospital, as at other debarkation hospitals. Special expertise was needed for the rapid sorting of large convoys. If the convoy was small, two or three reasonably well trained orthopedic surgeons could examine the casualties and sort them out promptly. As the war progressed, however, fewer and fewer officers had to see larger and larger numbers of casualties in shorter and shorter periods of time. The certain flair needed to accomplish this task was developed promptly by Captain Mech, Lieutenant Rosenfeld, and other officers. As their experience increased, they became able to walk through groups of 200 to 300 patients and evaluate their status, partly from their records and the data on their casts, but partly also from their general appearance. Even officers who remained on the orthopedic service for less than a year and who arrived entirely untrained in orthopedic surgery developed remarkable ability in the art of triage.

The first convoy from overseas received at Halloran General Hospital numbered 250 casualties and it took all night to accomplish its triage. Later, it was possible to process 1,200 patients in 5 or 6 hours. On one occasion, early in 1944, 250 casualties arrived in a convoy, all with casts in poor condition and overdue for changes (not because of carelessness in the original application, but because of delays en route). The convoy arrived late on Saturday night. Within 24 hours, every cast had been changed, and every casualty was in good condition and ready for further evacuation.

Components of Processing

While casualties were being processed, roentgenograms were taken as ordered. They were not taken routinely, but only as they seemed indicated by the clinical findings, the patient's general status, the comments on his chart, and the condition of his cast. A substation of the X-ray department was located on the orthopedic floor of the reception building, provided with portable X-ray machines and a developing room, and staffed with a team of radiologic officers and enlisted men.

Policies concerning change of casts varied from hospital to hospital. At a few, casts were removed routinely, for direct inspection of the wound. At others, they were removed only when shortening and angulation were evident. In most hospitals, however, the cast was removed only if there was some special indication, such as breakage, softening, a foul odor, discomfort, or soiling from discharges. The cast on a compound fracture, to be effective, had to be tight-fitting. Otherwise, position was lost, motion at the fracture site was possible, and healing was impaired.

To change a cast took considerable time and skill and those which seemed satisfactory were seldom changed, one reason being fear of loss

of position during the procedure. If the cast had to be changed and the fracture was in poor position, an attempt might be made to improve matters while the change was being effected, but this was not done if it required a trip to the operating room. At Halloran General Hospital, casts were changed in the operating room only if the patient had a long train trip before him.

At this hospital, sometimes as many as a hundred casts a day were changed, but in view of the thousands of patients processed here and at other hospitals, the proportion was really small, and changes because the casts were not properly applied originally were relatively few. At Stark General Hospital, Charleston, S.C., between 12 September 1944 and 13 December 1945, 13,288 returned casualties were processed, 6,940 of whom had orthopedic injuries. It was necessary to change only 791 of the casts before further evacuation. Experiences at other debarkation hospitals were similar.

Evacuation

The morale of returned casualties was outstanding. It was exceptional to find a soldier who did not think that he had received the best possible care that could be provided. Very few of them complained over delays in their evacuation from overseas. When a man was wounded and knew there was a chance that he would be returned to the States, he was naturally anxious to get there as soon as possible, but practically all of them understood and accepted certain delays as inevitable. If they had been unhappy about the delays overseas, they forgot their unhappiness once they were back in the Zone of Interior.

There was, however, one fly in the ointment. The original plan that returned casualties should be evacuated for definitive care to the appropriate hospitals nearest their homes did not always prove workable, for a number of reasons, the most important being that the geographic distribution of patients did not correspond with the distribution of the general population and the location of the hospitals. The situation was particularly unfavorable for orthopedic casualties because of their large numbers and the long convalescence required after such wounds. Unfortunately, the information given to casualties overseas continued to be that they would be sent to hospitals near their homes, and there was considerable dissatisfaction when it was found that this plan was not always practical.

Ambulatory patients scheduled for evacuation from Halloran General Hospital sometimes took matters into their own hands. The possibility of moving hundreds, sometimes thousands, of men out of the hospital on a given day was predicated on all the casualties' being in appointed spots at appointed times. If an ambulatory patient chose not to appear at that time and place, he simply hid out elsewhere until the train had left. If he was put on the train, he tried to leave it, and not infrequently he succeeded. At first, hospital authorities attempted to solve this problem by not in-

forming patients of their destinations until they were en route to them. The Inspector General, however, ruled that they had to be told where they were going. Once this regulation was put into effect, stragglers amounted to as much as 10 to 15 percent of some shipment loads, and the hospital was spotted with patients who had evaded evacuation and who were moved eventually to where they were to go only after the expenditure of much time, effort, and extra paperwork.

EVALUATION OF FIRST RETURNED CASUALTIES

Pearl Harbor

December 1941–January 1942.—An inspection of the casualties from Pearl Harbor who had been evacuated to Letterman General Hospital, San Francisco, Calif., was made on 26 January 1942 by Dr. (later Brig. Gen., MC) Isidor S. Ravdin and Dr. (later Col., MC) Perrin H. Long (*6*). Their report to The Surgeon General supplemented an earlier report of a visit to Pearl Harbor on 17–22 December 1941 (*7*).

Casualties with fractures observed at Tripler General Hospital, Honolulu, Hawaii, and the Station Hospital at Schofield Barracks had been treated by the open method, with debridement; an attempt to secure good alinement; coverage of the wound with petrolatum-impregnated gauze; and splinting with the Jones or Thomas splints or with plaster casts, which were not complete. Sulfanilamide was used both locally and systemically. The absence of suppuration, induration, and lymphadenitis or adenitis was most impressive 10 days after injury and was equally impressive when the patients were observed later at Letterman General Hospital. There was every reason to expect good functional results. The hospital staff stated that they had never seen serious injuries look so well and progress so smoothly, and Dr. Ravdin and Dr. Long concurred in this opinion, attributing the good results to good management and to sulfanilamide therapy.[3] The initial enthusiasm of these highly experienced observers for the sulfonamides is discussed in detail elsewhere (p. 143).

They found the management of the casualties from Pearl Harbor equally efficient at the Naval Base Hospital in Honolulu, where a modification of the Orr-Trueta technique was being used.

January–February 1942.—Casualties from Pearl Harbor hospitalized at Mare Island Naval Hospital, Vallejo, Calif., and Letterman General Hospital were visited on 26 January 1942 and again on 19 February 1942, and their status was reported on 19 February 1942 by Dr. LeRoy C. Abbott to Dr. George E. Bennett, Chairman of the Subcommittee on Orthopedic Surgery, Committee on Surgery, National Research Council (*8*). Among

[3] In a number of instances, wounds that were clean on the admission of the patients to Letterman General Hospital were being treated with BIPP (bismuth, iodine, petrolatum paste) gauze or pads. The wounds remained clean, but the BIPP made roentgenologic examination difficult, and the method was not recommended, on the ground that it had not proved useful in World War I and had found no general acceptance in the years between the wars.

the official visitors in January were Dr. Ravdin, Dr. Long, and Capt. (later Rear Adm.) Frederick F. Hook, MC, USN. Others who made visits included teaching personnel from the University of California Medical School, San Francisco, and staff members of the University Hospital and the local Children's Hospital.

The management of the 16 amputations in the 70 patients observed is discussed elsewhere (p. 926).

There were 72 compound, comminuted fractures, all with extensive associated wounds of the soft parts, in 63 patients. The 61 fractures in the lower extremity consisted of 10 of the femur, 18 of the tibia and fibula, 14 of the tibia, two of the fibula, three each of the ankle and the malleoli, seven of the os calcis, two of other bones of the tarsus, and one each of the patella and the astragalus. A few of the injuries had been caused by falls or by being thrown against some object, but all of the others were combat-incurred.

Emergency measures consisted of the application of sterile dressings after the wound had been sprinkled with sulfanilamide powder. The timing of initial wound surgery varied from 15 minutes to 60 hours after wounding, the variations being due to logistical circumstances, the number of casualties awaiting treatment, their priorities, and the facilities available. Surgery was confined to local excision of devitalized tissue. Sulfanilamide was again applied locally and was also used systemically. A few wounds were closed primarily, and a few others were closed later by "secondary" (later to be termed "delayed primary") closure. Most were held open with petrolatum-impregnated gauze.

The records, corroborated by the patients' statements, indicated that splints were not always used for transportation.

At the time of the first visits to the Pearl Harbor casualties (January 1942), no really accurate data could be obtained regarding the presence of infection. The degree of motion in adjacent joints, the degree of muscle atrophy, and the presence or absence of motion between the bony fragments were seldom recorded, and much reliance, therefore, had to be placed upon observation of the patients, their own statements, and the statements of the ward officers.

Within these limitations, the visitors concluded that the general well-being of the patients on their arrival in the Zone of Interior was "nothing short of being remarkable." The statements of the ward officers who had examined the wounds when the patients were received, combined with the excellent appearance of the patients, suggested that their wounds were healing well. The only really ill patients were four or five with infected knee joints which required drainage, in one instance three times. Another infection subsided promptly when the necrotic patella was removed. There were six other infections of other areas, all moderate, with moderate purulent discharge. Considering the nature of the emergency, the facilities available, and the conditions under which the surgeons had worked, the incidence of infection was considered highly creditable. A few later cases of osteomyelitis were expected, but it was thought that most of them would be well localized.

The results in these 72 fractures suggested that the ideal treatment for compound, comminuted injuries was the early application of sulfanilamide to the wound; early and thorough debridement; a second application of sulfanilamide; oral sulfonamide therapy; and simple traction splints for transportation. Under average circumstances, wounds did better if they were left open (as the later massive wartime experience proved) and if the injured extremities were immobilized by plaster. The experience with traction immediately after wounding was not impressive in this group, and, according to the patients' descriptions of their treatment, it was usually replaced by plaster within a few days. Six of the 10 fractures of the femur in the group showed various degrees of shortening and two others showed gross angulation. Only the two fractures in skeletal traction had good alinement and full length. It was concluded that only effective traction would produce good results in fractures of the femur.

Only three of the 18 fractures of both bones of the leg, and only one of the 14 fractures of the tibia alone, showed appreciable shortening. In these 32 cases, there were six fractures which showed sufficient angulation to require correction. In some compound, comminuted fractures of both tibia and fibula, with extensive soft tissue damage, fixation in plaster applied directly to the skin produced adequate length and alinement. In a few other less extensive injuries, good results could probably have been secured by adequate traction alone, especially if only the tibia was involved. Such fractures might angulate, but the intact fibula served as an effective splint and prevented overriding.

All seven fractures of the os calcis in these Pearl Harbor casualties were in Navy personnel and had been caused by explosions under the deck; the entire explosive force was expended against the under surface of the heel, and the bones were shattered. In two instances, the injuries were bilateral. No attempt at reducing these fractures had been made at Pearl Harbor, and all late attempts at reduction at the Mare Island hospital had accomplished nothing. Considerable permanent disability was anticipated in all of these cases.

Fractures of the upper extremity had all been treated by immobilization in plaster and results generally were good.

North Africa

The first casualties from North Africa were received in Zone of Interior hospitals in December 1942. The first convoy of these patients reached Moore General Hospital, Swannanoa, N.C., 21 days after the invasion, after debarkation at Charleston. The wounded had been taken directly from the three points of invasion onto boats, cruisers, and battleships, and had been given first attention in the sickbay. Wounds were cleansed and dressed, and fractures were immobilized in plaster. No roentgenograms were taken on the voyage back, for fear of disclosing the position of the ships to enemy submarines.

The patients, although they had all been in plaster for 3 weeks, without redressing, were in remarkably good condition. The odor emanating from their casts, though strong, was "laudable," in the opinion of the Chief of the Orthopedic Section, Maj. (later Lt. Col.) Frank G. Murphy, MC, who was a disciple of Dr. H. Winnett Orr and had often employed his technique in osteomyelitis in civilian life. In Major Murphy's opinion, the con-

dition of these patients was "a marvelous example of the soundness of closed treatment for open fractures." Some were in splints and others in single- and double-spica casts. Granulation tissue was profuse, and some patients had purulent discharges, but in not a single instance were any of the cardinal signs of inflammation present.

After roentgenograms had been taken of each casualty through his cast, the cast was removed in the operating room, under sterile precautions. An occasional shortening of the limb, with angulation and with no callus, was corrected under anesthesia. In some instances of mild overriding of the fragments, union was in progress and there was a surprising amount of soft callus. When the overriding displacement was no more than one-half to 1 inch and there was callus formation with side-to-side apposition, union was allowed to progress.

Debridement was performed at Moore General Hospital only if it was necessary. It was never "harsh," and every attempt was made to preserve healthy granulations. The wounds were then packed with petrolatum-impregnated gauze, followed by the application of additional dressings and plaster, frequently to the consternation of hospital personnel who had had no previous experience with the Orr treatment. There were no complications reported in any of the patients thus treated.

SURVEY OF RETURNED CASUALTIES

During 1944, an elaborate project was planned for the evaluation of the status of returned casualties, to include not only examination of records and replies to a questionnaire but also visits to hospitals, personal examination of patients and their records, and a followup of at least 6 months in each case. For a number of reasons, the project could not be carried out as planned, but a questionnaire was sent out, and the following remarks are based upon the replies received in response to it from 22 general hospitals (Battey, Rome, Ga.; Billings, Indianapolis, Ind.; Bushnell, Brigham City, Utah; Crile, Cleveland, Ohio; Deshon, Butler, Pa.; DeWitt, Auburn, Calif.; Gardiner, Chicago, Ill.; Halloran; Hammond, Modesto, Calif.; Harmon, Longview, Tex.; Kennedy, Memphis, Tenn.; Letterman; Lovell, Ayers, Mass.; Mayo, Galesburg, Ill.; McCaw, Walla Walla, Wash.; Moore; Nichols, Louisville, Ky.; Oliver, Augusta, Ga.; Schick, Clinton, Iowa; Stark; Torney, Palm Springs, Calif.; and William Beaumont, El Paso, Tex.), and also from three Service Commands (Fifth, Sixth, and Ninth), which consolidated their reports. There is thus some slight overlapping of data, but since this is a clinical and not a statistical survey, it is not regarded as of any great consequence.

The questionnaire covered the following points:

1. Date, hospital, reporting office, name and serial number of patient, registry number, diagnosis.
2. Date and hour of injury, date and hour of initial operation, interval in hours

between injury and initial wound surgery, date of delayed internal fixation, interval in days between injury and final operation, material used for internal fixation.

3. Condition of wound before final operation overseas and in the Zone of Interior.
4. Definitive procedure.
5. Penicillin therapy (dosage, duration).
6. Estimated result 6 months after final operation, including union, fixation material, presence or absence of infection.
7. Evaluation of internal fixation as good (+), poor (−), indifferent (#).
8. Additional details of history, personal opinions, other comments.

With very few exceptions, the opinion of the orthopedic surgeons who participated in this survey was that casualties from overseas were received in condition ranging from satisfactory to superb. The good results were explained not only by the competent management these men had received in the Zone of Interior, it began with the excellent initial surgery and general care they had received overseas. Without doubt, there had been careful planning. Certain odds were in favor of the casualties, it is true: They were, as already emphasized, for the most part young men, in robust health, with quick powers of recuperation. But these favorable circumstances did not alter the fact that, in spite of a few specific adverse comments, the general opinion was overwhelmingly that orthopedic care had been sound, competent, and excellent.

Certain comments might be cited to support these generalizations:

"Condition generally good." "General condition satisfactory." "Condition extremely gratifying." "On the whole, preparation and transportation were excellent, and the status of arrivals was generally satisfactory." "There is little to criticize. Most casualties arrived in excellent condition and work was of a superior caliber." "Their condition is satisfactory except for a few joints put up in spica casts in too much flexion. Practically all, however, are received in good condition." "The men are invariably in good condition unless circulatory changes are present. Their management is on the whole very satisfactory." "In general * * * preparation of patients for evacuation from the European Theater of Operations is extraordinarily well done and transportation is accomplished with a high degree of comfort * * *. The condition of the returned casualties is generally satisfactory." "On the whole, these men arrived in eminently satisfactory condition." "The whole program worked out very smoothly, and both general and orthopedic surgery was good * * *. In general, sound and expert care, with exercise of expert and painstaking judgment, has resulted in good results." "Casts are well applied to the tibia and fibula. They are inadequate in only 5 percent of fractures of the humeri and only 5 percent of fractures of the upper third of the femur." "Almost without exception patients * * * had unbroken, efficiently and adequately padded casts, with no more than one or two pressure sores." "Practically without exception the plaster casts were well applied and molded to the part involved. Immobilization was complete and efficiently maintained * * *. Men arrived in excellent condition, with few exceptions. Only one or two instances of loss of position in transit. Affected portions well splinted and immobilized, with immobilization of adjacent joints."

Other overall comments were as follows:

1. Some patients received with infected compound fractures, debilitated and in poor general condition, had been en route for several weeks, and their status could be attributed to the timelag rather than to any deficiencies in their original care. This ex-

planation held most frequently for casualties from the Pacific before air evacuation was developed.

2. Infection was very frequently, though not invariably, associated with delayed debridement, which was usually delayed because of combat conditions and not personnel error. Good results, however, were often obtained in the most unlikely circumstances, such as in the soldier who applied his own first aid on the field, was not removed from the field for 10 hours, and did not undergo debridement for another 38 hours.

3. When sequestration was present, the question always arose whether the original debridement had been radical enough. The implications of this and similar comments were not always fair; what might have seemed very good surgery to the frontline surgeon overseas sometimes did not seem so good weeks later to a surgeon in the Zone of Interior.

4. Internal fixation (p. 377) done as a secondary, delayed procedure was generally satisfactory. As a primary procedure, it was of doubtful value, and the indications for it were not always clear. The excellent results sometimes reported from it often seemed to be achieved in cases in which the justification for it was not evident.

5. There was unquestioned improvement in the status of returned casualties after penicillin came into general use overseas. About the time it was introduced, however, patients began to be received whose wounds had been closed 3 to 8 days after debridement by delayed primary wound closure. They were in excellent condition. While penicillin was extremely effective in the management of infections, there was sometimes a tendency to put too much faith in it. When, for instance, a patient with suppurative arthritis after a compound fracture of the patella promptly recovered under penicillin injection but his infection flared up with equal promptness when it was discontinued, the inference seemed fair that he needed further treatment and that his evacuation should have been delayed.

6. The general impression was that surgeons in field and other forward hospitals could probably do no more for their patients than they are already doing. Occasionally, however, it seemed that at base hospitals, where casualties were sometimes held for weeks or even months before evacuation, more might have been done for them. The probable explanation was shortage of orthopedic personnel.

Colonel Carpenter well summarized the opinion of Zone of Interior orthopedic surgeons on the conditions of returned casualties. Almost all of them, on their arrival, showed evidence of excellent primary care and good judgment during transportation. In general, surgical care followed official directives and was well done. Circumstances were not always controllable, but it was impressive to observe the good condition of most patients when the dictates had been met of efficient first aid, ample plasma and blood, early debridement, and nonsuture of the wound. The few patients who were severely infected were chiefly those who had not had sufficient plasma and blood to maintain their physical status, in whom debridement had been unduly delayed, and whose wounds had been closed at debridement. Neither the sulfonamides nor penicillin was a substitute for good surgery.

By the end of the war, Colonel Carpenter noted, "* * * it was exceptional to receive a patient in anything but good condition. Of the many thousands I saw personally, and the many other thousands treated under my supervision, I cannot recall a single patient who had any permanent damage because of poor treatment or poor management during evacuation."

RECOMMENDATIONS

A summarized report of the replies to the December 1944 questionnaire published in the April 1945 issue of *The Bulletin of the U.S. Army Medical Department* (*9*) began with a comment on the generally excellent condition in which casualties were returned from overseas. Certain frequent and preventable errors were listed, with special emphasis on erroneous casting of the hands and toes (p. 362 and 763). Recommendations made and special points emphasized were as follows:

1. The forearm should never be immobilized in supination but always in the neutral position or in slight pronation. This practice was especially important when there was infection about the elbow, with risk of ankylosis.

2. Patients should be instructed in the technique of static muscular contraction, which could be performed under plaster and would expedite recovery. Exercises were particularly important when the quadriceps was involved.

3. Active swinging exercises should be begun early when hanging casts were used for fractures of the humerus.

4. Equinus was not common, but when it occurred, the resulting disability was difficult to overcome. The ankle should always be placed in neutral position.

5. Fractures of the upper tibia were often best managed in a spica.

6. There was some disagreement concerning flexion of the knee, which was often necessary to prevent rotation of the fragments. If it was thought necessary, it should be slight, since persistent flexion interferes with function and is difficult to correct.

7. Fractures of the femur were kept in traction in the Communications Zone overseas until union had advanced far enough to permit safe transportation in plaster unless there was no possibility that union could occur before the patient's arrival in the Zone of Interior. Subtrochanteric and intertrochanteric fractures, in particular, tended to develop union with deformities that were difficult to correct.

8. Delayed internal fixation was performed in a number of cases before wound healing. This technique should be reserved for carefully selected cases in which the indications were clear cut. Exact data were not available when this summary was prepared, but at this time, the removal of foreign metallic fixation material was estimated to be necessary in from 25 to 40 percent of the cases in which this technique had been used, to end drainage and promote wound healing.

Certain of these errors are commented upon at greater length in the following pages, the comments and recommendations being derived from the December 1944 questionnaire. A few hospitals provided specific numerical data. The majority did not, which is unfortunate, since small, individually analyzed series are often more illuminating, and generally more indicative of the true situation, than larger official series.

ASPECTS OF OVERSEAS EVACUATION

Timing.—There was general agreement that it was the best policy to hold casualties with fractures of the long bones, particularly the femur, overseas long enough for the fractures to become frozen before the application of the cast for transportation. Fractures of the lower third of the femur were not transportable before 8 weeks; with earlier evacuation, position was likely to be lost. On the other hand, a tendency was noted to hold some casualties overseas too long, a policy that had two adverse effects; namely, the development of stiffness in the joints and loss of the optimum time for correction of malpositions. Because of the difficulties of transportation until late 1944, these effects were especially notable in casualties received from the Pacific areas. The policy of holding femurs overseas until they were frozen had to be correlated with available bed capacity and the needs of incoming casualties. During the Battle of the Bulge, this consideration was most important.

Evacuation had to be timed carefully in casualties who had shown a tendency to excessive oozing or intermittent secondary hemorrhage (p. 321).

Records.—Records were often not so complete as they should have been, even making allowance for the circumstances under which they had to be kept. Comments were particularly bitter about the practice of keeping entries on separate slips, in envelopes; every time they were removed for study, they were scrambled and some items were lost. The proposal that records be kept on folding pads, or that the slips be arranged chronologically and stapled together, was not tested, but neither seemed to be a practical solution.

It would have been useful if serial roentgenograms had been available at stations at which casts were to be changed during evacuation. Their absence varied from merely annoying to extremely important. Their unavailability during transit sometimes interfered with continuity of treatment. In spite of strenuous efforts to overcome it, this problem was never fully solved during the war (*10*).

The loss of records and roentgenograms would have been more serious in many instances except for the increasingly general practice of annotating the casts to show the location and type of injury, dates of wounding and of changes of casts, diagrams of the fracture, and other useful data.

Theaters of origin.—Many hospitals found no material differences in the condition of returned casualties in relation to their theaters (areas) of origin. Many others, however, found that those received from the Pacific areas, particularly the Southwest Pacific Area, were in less good general condition, and their wounds were in less good local condition, than those received from the Mediterranean and European theaters. These observations almost universally were explained by the less favorable circumstances for care of the wounded in the Pacific areas and the far longer period of

transportation, even when air evacuation was introduced. On the whole, casualties flown to the United States were, naturally, in better condition both generally and locally than those who had undergone long sea voyages.[4]

In evaluating the status of casualties returned from the Pacific, the circumstances of warfare and medical care in those areas always had to be borne in mind. At the best, it was only in a relatively small proportion of cases that such factors as hospital facilities and equipment, long distances, environmental conditions, personnel, and consultants in those areas could be equated with similar factors in the other theaters of operations. Orthopedic loads were heavy, trained orthopedic specialists were few, and only casualties most urgently in need of specialized orthopedic attention were likely to receive it. Moreover, the complex organization of the Pacific areas made it impossible for the Chief Surgeon, Southwest Pacific Area and U.S. Armed Forces Far East, to force his ideas upon the various commands under him (*11*). Even when his recommendations were accepted, they were not always carried out by task force surgeons. These considerations obtained with orthopedic surgery just as with the general care of casualties.

The most important point in the status of all casualties when they arrived in the Zone of Interior, no matter what the point of origin, was their condition when transportation was undertaken. There was a notable improvement in each successive campaign.

Because of the collapse of the ambitious plans for a survey of returned casualties, overall statistics are not available. The following figures on osteomyelitis of certain bones in respect to theaters of origin are presented because they show the very creditable results achieved by good management in the prevention of infection.

Figures available from 13 general hospitals in the Zone of Interior for casualties received from the European theater show osteomyelitis in 146 of 636 fractures of the femur, in 237 of 797 fractures of the tibia, and in 82 of 468 fractures of the humerus.

Figures available from nine general hospitals in the Zone of Interior for casualties received from the Mediterranean theater show osteomyelitis in 32 of 102 fractures of the femur, in 40 of 139 fractures of the tibia, and in 10 of 55 fractures of the humerus.

Figures available from 10 general hospitals in the Zone of Interior for casualties received from the Pacific Ocean Areas are too few and incomplete to be significant, but they are cited as indicating, even under the unfavorable circumstances that prevailed in these areas, the same trend toward a low incidence of osteomyelitis evident in the European and Mediterranean theaters. Osteomyelitis occurred in 17 of 54 fractures of the femur, in 29 of 97 fractures of the tibia, and in eight of 36 fractures of the humerus.

Associated wounds.—Vascular complications, as already mentioned

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[4] During the Korean War, the former Colonel Carpenter served as civilian Consultant in Orthopedic Surgery at Fort Campbell, Ky., where he observed many returned casualties. Their wounds were of the same type as those he had treated during World War II, but the condition of the patients was somewhat different because most of them had been flown back. In his opinion, much had been learned about the transportation of casualties from the World War II experience, and the lessons learned in that war concerning the primary treatment of orthopedic wounds were being excellently put into practice in the Korean War.

(p. 10), were extremely uncommon in returned orthopedic casualties, since almost all of them had been handled overseas. An occasional patient was encountered with a traumatic aneurysm, but it was practically always possible to transfer him to a vascular surgery center. Combined vascular-orthopedic conditions are discussed in the volume in this series dealing with vascular surgery (*12*).

Combined neurosurgical-orthopedic conditions are also discussed in other volumes in this series (*13, 14*), but one or two important considerations should be mentioned briefly.

1. In all such cases, immediate consultation with the neurosurgeon was requested.

2. If the wound had not been closed and the compound fracture was not united, neurosurgery had to wait while the orthopedic surgeon closed the wound and handled the fracture. If the wound was closed and the patient presented both nonunion and a peripheral nerve injury, the neurosurgeon sutured the nerve before bone grafting was attempted. The time saved by this plan could make the difference between good nerve regeneration and none at all.

3. If the gap in the nerve was of considerable extent, shortening of the humerus by as much as 2 inches was done without a qualm. Shortening of the lower extremity was not acceptable except for occasional slight overlapping of the bones if repair of the sciatic nerve was the problem.

4. Occasional instances of nerve injury resulted from too forceful application of tourniquets. A great deal of damage could result in a very short time, and all personnel were warned against this practice, however urgent the need for the tourniquet might be.

Internal fixation.—As a matter of convenience, the whole subject of internal fixation in Zone of Interior hospitals is discussed in a separate chapter (p. 377). It might be repeated here, however, as already intimated, that the results reported in the December 1944 survey varied widely but were generally unfavorable.

Transportation practices.—Although there was general approval in the December 1944 survey of the casts applied for transportation, certain rather frequent errors might be mentioned, in addition to errors concerning splinting of the hands (p. 362) and feet (p. 763).

1. A number of long-leg plaster casts and casts of the feet showed evidence of weight-bearing, which should not have been permitted. The cast was damaged, the foot and ankle became edematous, and the patients complained of pain at the fracture site. Equally unwise was the occasional practice of converting long-leg casts into short casts in fractures of the tibia while the patients were en route to the United States.

2. Unpadded casts were not suitable for transportation and they were used only occasionally. As a result, pressure sores were seldom encountered and pressure paralysis was also not a usual complication.

3. If windows cut in the cast for access to the wound were not padded

adequately with felt or dressings, pressure was likely to cause edema above the wound.

4. Some casts were ineffectual because they had become soft as the result of profuse drainage. It was suggested that, whenever excessive drainage was anticipated, posterior reinforcements should be used.

5. Some casts were originally applied too loosely to achieve satisfactory immobilization. This was especially true of fractures of the spine in all theaters and areas and in casualties from the Pacific, who had often been 6 to 8 weeks in transit.

6. Casts applied with the idea that the patients could be ambulatory in them were sometimes too thick and heavy for that purpose.

7. A rather general adverse criticism, to which attention is called elsewhere (p. 16), concerned failure to instruct patients in muscle exercise to be carried out during transportation, particularly quadriceps exercises.

8. The regulation that all transportation casts must be bivalved, so that they could be readily removed when the need arose, was not always heeded. The damage was slight, however, because by the time transportation casts were applied, edema had usually disappeared and the casts were likely to be rather loose.

Transportation traction.—In a few Zone of Interior hospitals, casualties who had been transported in external skeletal traction were received in good condition, without infection, and in excellent roentgenologic alinement. These hospitals were the exception. In one hospital, about half of the patients thus transported had infected wounds and poorly alined fractures, while two who had traveled in the Roger Anderson apparatus had large abscesses about the pins. In another hospital, of six patients received with externally fixed fractures, five showed absorption at the pinholes and had open, draining sinuses. Infections about pins were usually more serious than infections about wire. Many patients whose fractures had been pinned required saucerization and excision of sequestra, with plastic closure of the wound, even when their fractures had healed.

In an analysis of orthopedic material in February 1945, Col. Robert H. Kennedy, MC, Consultant in Surgery, Second Service Command, commented with approval on the decreasing use of traction for transportation (*15*). He considered that the decrease was readily explained by the uniformly poor results of pins or wires incorporated in plaster. For his own part, he had yet to see a patient arrive in the Zone of Interior in external skeletal traction without infection about the pinholes. The infection usually was not related in any way to the surgical workmanship overseas. Practically always, it was the result of prolonged periods of transportation (when this method was most popular, air transportation was just beginning to be used), with changes of position during it. Colonel Kennedy had

never heard of use of the Stader apparatus overseas and hoped that he never would.[5]

Transportation in half-ring splints was equally unsatisfactory. It was painful and uncomfortable.

Delayed primary wound closure.—Delayed primary wound closure did not become official policy in the Mediterranean theater until the spring of 1944 (p. 255) and never became official policy in the Pacific areas, though it was rather generally practiced late in the war. Since a minimum of 2 months, and often considerably more time, usually elapsed between wounding and the return of the casualty to the Zone of Interior, it is easy to understand the small number of cases reported in the December 1944 survey. At this time, some hospitals had no patients who had been treated by this technique.

In spite of the limited number of cases, however, and the inadequacy of the record, there was almost universal agreement about the excellent results achieved by this new method. The only discordant note, in fact, came from the chief of surgery in a single hospital, who continued to advocate the Orr-Trueta method, by which wounds were allowed to close themselves. Comments from other observers ranged from satisfactory to enthusiastic. One chief of section reported that if wound closure was successful, it might save as much as 6 months' time in cases in which secondary surgery might be necessary, while if it was unsuccessful and drainage ensued, little was really lost. Other orthopedic surgeons took the same position, that if the procedure failed, nothing was really lost. Casualties received with closed wounds that were draining were still in better condition than those whose wounds had not been closed. Some surgeons commented that the procedure was really more successful than the statistics indicated. At William Beaumont General Hospital, for instance, in eight cases of frank osteomyelitis, successful closure had been accomplished in six, and while one of the two remaining wounds continued to drain intermittently, there was no bone destruction evident roentgenologically.

Analysis of the cases reported in the December 1944 survey showed that it was usual for wounds of the upper extremity and the thigh to heal more promptly than wounds over the tibia when closure had been done in the optimum period (4 to 10 days after debridement). Drainage in the latter group of fractures sometimes persisted for 8 to 10 days, and complete closure sometimes took 2 to 4 weeks.

Skin grafts.—Opinions on the use of split thickness skin grafts as an aid to wound closure were generally favorable, ranging from "reasonably

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[5] It is unfortunate that the use of the Stader, Roger Anderson, and Haynes apparatus was ever countenanced overseas. Most reports concerning it, in the Zone of Interior and overseas, were extremely unfavorable. Almost the only exception was the report by Capt. Charles K. Kirby, MC, and Capt. William T. Fitts, Jr., MC, from the 20th General Hospital in India (*16*). Over the 2-year period ending on 1 April 1945, transfixion pins and wires were used 342 times in 333 fractures of the long bones. There were only 12 complications in the 305 injuries followed up; 11 of the 12 were considered avoidable. There were no known complications in the other 37 cases, but the followup in them was inadequate.

successful" to Colonel Kennedy's statement that great credit was due plastic and other surgeons overseas for grafting of large compound wounds within 7 to 21 days after injury (*15*). With few exceptions, he continued, the grafts were successful, and prolonged wound drainage and secondary infection were eliminated. Other surgeons pointed out that, when total success was not achieved, 50 percent or more of closure was likely to be accomplished even in the face of infection; that soft tissue contractures were usually avoided; and that bony tissue as well as soft tissue was conserved.

Joints.—Just as in other aspects of management of orthopedic casualties, comments on the status of the joints in the December 1944 survey were generally good. The following comments are representative:

> "Condition generally good. Maintained in proper position of rest and function from physiologic standpoint. Very little evidence of fibrous ankylosis. After removal of cast, no criticism whatsoever in reference to immobilized joints." "Those joints not involved by destructive wounds were well mobilized and in good condition." "Good condition except for severe shattered fractures with large wounds involving the muscles and joints."

Stiffness was generally present in all immobilized joints, the degree depending upon (1) the duration of immobilization, which not infrequently was unnecessarily prolonged, and (2) the care taken before transportation to instruct the casualty in his own responsibility for the status of his joints by the performance of frequent, regular exercises. More attention was usually paid to exercises in the lower than in the upper extremity, but in neither area were they used as widely as they should have been. In some convoys, it was exceptional to find patients who had had any instruction at all in this regard. This particular omission resulted, in turn, in edema about the wound, muscular atrophy, periarticular fibrosis, and sometimes deformity serious enough to retard recovery and prevent return to full military duty. The association of excellent anatomic reduction in plaster with poor functional end results was greatly to be deplored. On the other hand, the majority of these comments were tempered by the realization, frequently plainly stated, that there was no alternative for immobilization during transportation, as well as by the fact that stiffness was inevitably more pronounced when fractures were located close to the joints.

While the condition of all joints came in for criticism at one time or another from one hospital or another, the most general criticisms concerned the errors, already mentioned several times, in immobilization of the hands and feet.

REGIONAL INJURIES

Shoulder.—Shoulder spicas were usually well constructed and not too heavy. Casualties who were provided with casts with two shoulder straps seemed to keep the casts in better position and to be more comfortable

than those whose spicas were supported by the injured shoulder alone. They also seemed to travel more comfortably when the degree of abduction did not exceed 60 degrees. Some extensive gunshot wounds of the shoulder put up in 90-degree abduction presented partial subluxation of the head of the humerus, in which full abduction of the humerus seemed to play a part. Some shoulder spicas were not made sufficiently long over the torso, with the result that the weight was carried on the shoulder rather than on the crest of the ilium.

Humerus.—In injuries of the humerus, unless the elbow was directly involved, motion was ultimately restored. The early use of hinges in an abduction arm cast was beneficial in fibrous but delayed union and could profitably have been instituted overseas in some selected cases, to restore elbow motion.

Very few instances of actual distraction attributable to the cast were observed when a hanging cast was used unless the cast was so heavy that separation of the fragments occurred. In such cases, the fractures were demonstrable by roentgenograms. Angulation at the site of the fracture was sometimes present when the cast was applied with insufficient flexion, or when the length of the sling was judged incorrectly, or when the original length had been altered by the patient or an attendant. Much dysfunction of the shoulder joint could have been prevented if patients in hanging casts had all been taught to lift their arms to shoulder level at intervals. The same exercise would have eliminated much of the edema seen in the fingers and hands when these casts were used.

Some observers believed that the most effective transportation in injuries of the shaft of the humerus was in a spica, with the arm in abduction. Most orthopedic surgeons preferred the hanging cast. A spica might be more comfortable immediately after injury, when evacuation was seldom effected, but later a hanging cast was more comfortable and more effective. Moreover, distraction of the humerus sometimes occurred in a spica but almost never, as just noted, in a hanging cast.

In the opinion of the surgeons at McCaw General Hospital, the single fracture that could be immeasurably benefited by a change in current management was a compound, comminuted, shattering fracture in the supracondylar or condylar region of the humerus. This was a fracture associated with a great deal of disability. It was not benefited by a shoulder spica or a hanging cast. The only way to reduce it and maintain alinement was to apply skeletal traction through the olecranon process, supplemented by the use during transportation of a shoulder spica with a light Bessemer steel outrigger. It was thought that this technique would eliminate a large percentage of disability and greatly reduce the need for future arthroplasty at the elbow joint.

Very extensive comminution of the upper end of the humerus was often followed by osteomyelitis associated with avascular necrosis of the head. Prolonged conservative therapy, which was generally preferred to ex-

cisional surgery, eventually resulted in most cases in revascularization of the head, with final union, even though fragmentation extended over a distance of 6 to 8 inches. In such cases, late, rather than prompt, sequestrectomy was considered best.

Elbow.—Fractures about the elbow were commonly received in subtotal extension, at an angle of 120 to 140 degrees, which was a debatable position. Experience showed that restoration of motion in the most essential arc (right angle to full flexion) was more difficult to attain with immobilization in this position than in elbows put up in greater flexion. Some fractures about the elbow were also immobilized too far backward.

Fractures of the lower third of the humerus and other fractures about the elbow resulted in many stiff joints. There were numerous brilliant recoveries, it is true, but the pessimistic opinion of some orthopedic surgeons, that function was seldom recovered completely in compound fractures about the elbow, was not without basis. Some residual stiffness was frequently unavoidable in view of the nature of the lesion and, more especially the necessity for fixation, the duration of which was entirely beyond the control of orthopedic personnel.

Forearm.—Fractures of the forearm generally were well handled, in spite of certain technical difficulties in instituting traction and controlling pronation and supination during transportation. One common error has already been mentioned several times, the extension of the cast beyond the metacarpophalangeal joints, which was compounded by failure to warn the patient of the importance of exercising his fingers. The second error was faulty positioning. A number of patients with severe compound comminuted fractures of the mid radius and ulna arrived in the Zone of Interior with their forearms put up in complete pronation. Because of the type of injury, synostosis developed and the bones were fixed in such poor functional position that surgical correction was necessary. In all such cases, a position of mid pronation was best.

Femur.—The majority of combat-incurred fractures of the femur received from overseas were severely compounded and comminuted. In many instances, there was a considerable loss of bone, and often a considerable loss of soft tissue also. A small number of casualties had concomitant vascular injuries which required attention (though the most serious vascular injuries had necessarily been cared for overseas). A larger number had associated nerve injuries, chiefly injuries of the sciatic nerve. Associated wounds of the bladder and intestine frequently required immediate attention. Some casualties were malnourished and septic. A few had developed personality problems.

In view of these facts, it is not surprising that more problems arose in connection with fractures of the femur than with fractures of any other bone. It should be emphasized, however, that the group received in poor condition from the standpoint of their femoral injuries alone was very small. Once the program of delayed primary wound closure had been insti-

tuted overseas and the closed plaster program discarded, the majority of these casualties were received with wounds that had been closed, by the use of split-thickness skin grafts if necessary, and that were clean and well healed. The most serious infections occurred in fractures in which (1) debridement had been impossible or inadequate; (2) resuscitation had been faulty and plasma and blood had not been used liberally enough; and (3) wounds had been sutured primarily.

Many fractures received in poor condition were the result of poor timing, for which, in most instances, no blame could be attached to their overseas care. Some casualties, often for valid reasons (p. 270), were evacuated before sufficient union had been secured for position to be maintained en route. The result was loss of alinement and, sometimes, complete displacement of fragments.

Once a fractured femur was taken out of traction after a sufficient period of immobilization and put into a plaster spica for transportation, the voyage should have begun at once. Instead, for military and logistic reasons, the waiting time was often excessive, particularly in the Pacific. If a spica was used and was applied when there was still considerable swelling in the thigh muscles, the situation changed as time passed and as the volume of the muscles decreased with absorption of hematomas and development of muscle atrophy. This could happen during delays in transportation. As the cast loosened further, alinement was lost, angulation and overriding of fragments were possibilities, and by the time the Zone of Interior was reached, callus might prevent correction of the displacement by traction or other nonsurgical means, and the surgeon would be forced to decide whether to accept a poor anatomic result or to refracture the bone. From the standpoint of timing, casualties received from the United Kingdom generally arrived in the Zone of Interior in better condition than those from other areas.[6]

Generally speaking, a casualty with a fractured femur was evacuated too early if the fracture had not been kept in traction long enough for it to maintain its position when plaster was applied. He was evacuated too late if the fracture had become sufficiently united in poor position to require surgical correction in the Zone of Interior. In a number of excessively comminuted supracondylar fractures, traction was discontinued too soon and excessive shortening and malunion occurred during transportation in plaster. Some fractures of the femur bowed within the casts in transit. Clinically, they had seemed solid enough overseas to maintain alinement in transit, but the impression was incorrect. When the patients arrived in the Zone of Interior, their fractures were too solidly fixed in malposition for

[6] The explanation is simple. Holding periods for general hospitals on the Continent were usually about 80 days. The majority of casualties with fractures of the long bones were at once evacuated to general hospitals in the United Kingdom Base, where the holding period was up to 120 days. This policy, as mentioned elsewhere, was violated only during the Battle of the Bulge, in anticipation of the large numbers of casualties who had to be provided for, though they did not materialize in the numbers expected.

correction to be accomplished by traction, and manual osteoclasis under anesthesia was necessary. This is not an easy operation.

More care should undoubtedly have been exercised in the supervision of fractures of the femur during transportation, especially on hospital ships. Unless the fractures were in an advanced state of healing, they should always have been kept immobilized until the patients reached Zone of Interior hospitals. Removal of the cast as early as 2 months after injury, as was done in a few cases en route, was without justification. More attention should also have been paid to the risk of refracture in femoral injuries; one patient, for instance, fell out of a wheel chair and refractured a femur that still displayed only limited union.

When a transportation spica was used, it was always a good plan to check the application by roentgenograms, to make certain that position had not been lost during maneuvers. A similar check was also wise if the spica had been applied for any length of time before the voyage, to be certain that atrophy of muscles had not caused loss of position.

Transportation was sometimes difficult in a double hip spica. The difficulty could be overcome by a complete change of cast or by extending the cast to the nipple line and immobilizing only the injured extremity. Many Zone of Interior hospitals considered spicas with crossbars the most desirable technique of transportation. Very few such casts broke en route, and pressure sores were almost unknown. Long-leg casts proved mechanically inadequate in the few instances in which they replaced spica or spica-and-a-half casts.

An appreciable number of intertrochanteric fractures were received with coxa vara deformity. This type of fracture readily loses position in plaster, and it was the opinion of many military surgeons that, in such cases, it might be better to postpone transportation in plaster until firm union had occurred or to use a transportation spica in which some form of traction was incorporated. Another plan was to use the most rapid possible form of transportation, to cut down the time necessarily spent in plaster.

Partial ankylosis was rather frequently associated with delayed union in fractures of the femur. The deformity was particularly conspicuous in the hip because the optimum position for ankylosis of that joint does not correspond with the optimum position for therapy. Because of the widespread—and entirely correct—use of abduction in the management of subtrochanteric fractures, the same position became routine in combat fractures of the hip joint in which ankylosis was to be anticipated. Initially, abduction was desirable to aline fragments and prevent dislocations of the hip. Later, it became the practice of some surgeons to leave the hip in the same wide abduction when early callus was forming. This was extremely unfortunate, for ankylosis in abduction produces a most undesirable type of lurching gait. In a number of such cases, it was necessary to use traction

and wedges to bring the thigh out of excessive abduction and back to neutral position.

In certain other combat injuries of the trochanters, the use of only a routine degree of abduction was often inadequate. As a result, the normal angle of the neck and femoral shaft was not restored, and though bony union ultimately occurred, it was associated with coxa vara, and osteotomy was required to reestablish pelvic-trochanteric muscular stability.

There was almost invariably limitation of motion of the hip joint after removal of the transportation plaster, no matter how well it had been applied. When plaster was used for longer periods than necessary, limitation was frequent. Infected fractures of the femoral shaft that extended into the knee joint and involved the quadriceps resulted in permanent limitation of even passive terminal extension. Not much attention seemed to have been paid to muscle tone and active joint motion either overseas or during transportation. Quadriceps tone was particularly poor. Much time and effort would have been saved in Zone of Interior hospitals if there had been a judicious use of exercises to the limit of safety overseas.

Fractures of the shaft of the femur managed by delayed primary wound closure usually arrived in excellent position and condition.

Knee.—The knee joint was another major—and frequently unsolved—problem, whether because of injury per se or because of the necessity for immobilizing it in fractures of the femur. When the transportation spica was removed, it was often difficult to flex the knee at the desired degree (10–15 degrees) so that traction could be instituted for the femoral fracture. Flexion deformities of the knee were also frequent in combat injuries.

No matter how carefully and correctly knee injuries had been treated overseas, the use of transportation plaster for days, and sometimes for weeks, caused definitive retrogression in knee function.

Leg.—Fractures of the tibia and fibula usually arrived in properly padded casts which were strong enough and comfortable enough for transportation and which held the bones in good position. The casts, however, were not always applied with the ankle in correct anatomic position, and rotational deformities of the shaft, as well as ankle deformities, resulted. A mild external rotational deformity after a gunshot fracture of the tibia produced nothing more serious than a flat foot. An internal rotational deformity, which was occasionally observed, was a serious handicap because of malalinement of the planes of the knee and ankle joint. The chief reason for the poor alinement was not lack of attention to the reduction of the fractures but rotation of the knee and thigh within the cast. If the leg was correctly splinted, with the knee in flexion, this problem did not arise. In one badly comminuted fracture with loss of stability, a tibial pin was used to control rotation of the upper fragment. The lower fragment was controlled by the foot portion of the cast, and the result was excellent.

More frequent use of longitudinal plaster splints incorporated in the

interior surface of the cast would probably have reduced the ridging occasionally seen when casts had been hastily and improperly applied.

The most serious joint difficulty in fractures of the bones of the leg arose from failure to maintain the foot at a right angle to the leg, especially when the ankle joint was also involved in the injury. Equinus contractures in tibial injuries could be remedied by wedging, but this method was not effective when the astragalus, ankle joint, or os calcis was involved. The necessary corrective surgery frequently had to be deferred because of the development of osteomyelitis in os calcis and tarsal injuries.

Foot.—In a few cases, for reasons not clear, the feet were received in equinus. It was difficult to bring them to the neutral position. Also in a few cases, flexion contractures followed failure of support of the plantar surface; nerve injuries were sometimes associated. In three known cases, prolonged disability resulted from the application of the cast in such a manner that the toes were dorsiflexed. Attention is called elsewhere to the easily avoidable error of hyperextending the toes (p. 269). Patients with peripheral nerve injuries of the lower extremity always needed toe guards.

Inversion of the heel was sometimes required initially to aline the ankle mortise, but if it became fixed in this position, a major handicap to gait had been created. The deformity might have been avoided if the initial position had been changed to neutral as soon as possible, under anesthesia if necessary. Surgery was the only possible definitive treatment.

Spine.—Minerva jackets were sometimes ill fitted and so loose that they did not immobilize the cervical spine. They were often in poor condition when the patients were received. These jackets had to be well trimmed in front, to preserve hyperextension, and well trimmed about the thighs, to avoid the discomfort caused by excessive length. On the other hand, if they were too short, they were ineffectual, and too little trimming was preferable to too much. Immobilization was more satisfactory when the jackets were fitted with a plaster band about the forehead.

It should be emphasized again that most of the criticisms described in the foregoing pages refer only to isolated cases or small groups of cases and should not be interpreted as generally applicable. The overwhelming majority of orthopedic casualties received from overseas arrived in Zone of Interior hospitals in a status ranging from satisfactory to superb.

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CHAPTER VIII

Osteomyelitis

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GENERAL CONSIDERATIONS

Official Department of the Army statistics show 22,604 hospital admissions for diseases of the bone during 1942–45, 16,226 of which were in the continental United States. In the total group, 6,465 admissions were for osteomyelitis, and 4,720 of these were in the continental United States. It is a fair presumption that a number—perhaps a significant number—of additional cases of osteomyelitis are lost in the 13,137 admissions for "other" diseases of bones, 9,377 of which were in the continental United States (*1*).

No details of pathologic process, management, or other aspects of osteomyelitis can be derived from the official statistics. These data, however, are available in several series of cases collected from various hospitals and analyzed from the standpoint of the reviewers' special interests.

It should be emphasized that practically all of the osteomyelitis observed in the Army in World War II was the result of combat-incurred injuries.[1] In a series of 150 cases studied by Lt. Col. Franklyn A. Rice, MC, at Billings General Hospital, Fort Benjamin Harrison, Indianapolis, Ind., there were 149 combat-incurred injuries and one instance of hematogenous osteomyelitis (*2*). The disproportion was entirely typical and makes even more ironic the amount of time and effort expended on the latter variety in the text on "Orthopedic Subjects," prepared by the Subcommittee on Orthopedic Surgery, Committee on Surgery, Division of Medical Sciences, National Research Council, in 1942 (*3*) (p. 36).

The precise incidence of osteomyelitis in World War II is impossible to determine, but, based on comprehensive studies of individual series of cases, infection in combat-incurred wounds of the extremities seems to have been in the neighborhood of 20 to 25 percent. This is highly creditable, for many of the wounds in this group were large and gaping, with extensive infections of both soft tissue and bones, and were often the site of serious

[1] Osteomyelitis of any of the long bones first appeared as a cause of rejection for service in the Army regulations issued on 15 March 1942. On 15 October 1942, this specification was changed to active osteomyelitis of any bone, or a substantiated history of osteomyelitis of any of the long bones within the past 5 years. On 1 February 1943, 5 years was changed to read "at any time." Men inducted with osteomyelitis through error, as a rule, were discharged promptly. *Orthopedic surgeons in World War II,* therefore, had very little experience in the management of civilian-incurred osteomyelitis in the Army.

bone losses. Medical officers who had seen such wounds in World War I frequently marveled that these men had survived and that their limbs were still in situ.

The relatively small number of these casualties, their survival, and the preservation of their limbs were easily explained by the excellent care they had received, supplemented by the liberal and correct use of plasma and whole blood and the sulfonamides and penicillin.

Other favorable considerations, as already mentioned, were that the majority of the patients with osteomyelitis were men in an age group, and with a physical status, that made them peculiarly responsive to treatment. Also, the type of osteomyelitis which they exhibited was secondary to compound fractures and was, therefore, fairly well localized, in contrast to the hematogenous variety formerly rather frequent in civilian life. Against these relatively favorable considerations were two factors almost never encountered in civilian life; namely, extensive comminution and extensive soft tissue destruction.

The ultimate impact of osteomyelitis in both World Wars is evident in the following data:

1. In the Minneapolis (Minn.) Veterans' Administration Hospital, over the period 1928–40, 94 amputations for this cause were performed on World War I veterans, who desired relief from recurrent disability and hospitalization (*4*). Between 1946 and September 1965, 116 amputations were performed for this cause in this hospital on World War II veterans. Had the incidence been the same as in World War I, the number of amputations on World War II veterans would have been several times greater.

2. As of 14 April 1965, the Department of Veterans' Benefits, Veterans' Administration, reported that available statistics showed that 264 World War I veterans whose major disability was osteomyelitis were receiving monthly benefits totaling $39,628 (*5*). Similarly, 2,258 World War II veterans were receiving monthly benefits totaling $177,008.50. The figures do not include osteomyelitis in other claims in which some other disability was considered more severe.

What the payments would have been if the World War II osteomyelitis situation had been what it was in World War I, from the standpoint of both incidence and management, is not possible to conjecture.

PATHOLOGIC PROCESS

Osteomyelitis was considered to exist whenever purulent drainage occurred from a wound that communicated with bone and that presented roentgenologic evidence of fracture or infection. Any bone might be involved, but the tibia and femur were affected most often. A wide variety of bacteria were recognized.

In 66 cases of osteomyelitis (in 64 patients) at DeWitt General Hospital, Auburn, Calif., (*6*), for instance, *Pseudomonas aeruginosa* (*Pyocyaneus*) was cultured 14 times; *Staphylococcus aureus* 10 times; *Staphylococcus albus* (facultative anaerobe) eight times; *Staphylococcus aureus* (hemolytic) seven times; *Escherichia coli*, *Para*

colon species, and *Proteus* species six times each; diphtheroids, *Aerobacter aerogenes*, *Streptococcus viridans*, and *Streptococcus pyogenes* (hemolytic) three times each; and *Streptococcus* species (nonhemolytic) twice.

It should be noted that a number of bacteria in this listing, as in listings from other hospitals, are not sensitive to penicillin. It was the general practice to use it in such cases, however, on the reasoning that if the usual invasive pathogens could be controlled by a bacteriostatic agent to which they were responsive, the nonresponsive organisms would be eliminated by the resistance of the host.

In spite of its relative infrequency, osteomyelitis was a very troublesome problem in World War II. The destructive nature of the causative missiles resulted in serious losses of bone substance, followed by infection of varying degrees, followed, in turn, by dense scar formation. The bone cavity was reluctant to heal, and the bone was usually so weakened that full function could not be expected without further surgery. Even if union occurred, refracture was likely unless the bone was reinforced by a graft. Soft tissues were also susceptible to recurrent infection and necrosis. In other words, osteomyelitis secondary to a combat wound, while sometimes trivial, might also imply deep infection; unhealthy granulations; varying degrees of interstitial fibrosis; and more or less involvement of the injured bone and adjacent bone structures. It was often not a hopeful picture.

Definitive surgery could not be undertaken until infection was controlled and granulation or scar tissue excised, procedures which required closure of the wound and adequate skin coverage and which themselves required preliminary surgery. If peripheral nerve lesions were associated, as they frequently were in injuries of the long bones, it was imperative to clear up the infection as promptly as possible, to permit neurosurgical procedures, since the longer the timelag between nerve injury and surgical repair, the poorer the prognosis for recovery of paralyzed muscle groups. The end result of bad timing and unwise or inadequate management might be crippling from stiffened joints, atrophied muscles, nonunion or delayed union, recurrent exacerbations of osteomyelitis, and pathologic fractures.

One warning, already mentioned elsewhere (p. 340), should be reiterated here: In the surgeon's enthusiasm for the use of the new techniques available to him in World War II, he had to bear in mind ultimate functional results. If it required 18 months to 2 years to clean up a wound, carry out skin grafting, and follow that operation by bone grafting, what would be the likely condition of the joints above and below the lesion at the end of this time? The chances were that they would sometimes be so fibrosed and ankylosed that good function would be impossible. It takes 9 to 12 months for a bone graft to grow proximally and distally, and a patient might sometimes end with better function of the extremity if he underwent prompt amputation. This was particularly true when the tibia was involved.

CLASSIFICATION

The classification of osteomyelitis used at Crile General Hospital, Cleveland, Ohio, was practical and useful (*7*):

1. Infection was limited to the separated bone fragments deprived of their blood supply, the extent of the involvement being determined only at sequestrectomy. If it was so limited, the suppurative process usually became quiescent after excision of the devitalized and necrotic fragments, and delayed primary wound closure could be effected later.
2. Infection was present within the muscle substance about sequestra and within the medullary canal, secondary to extensive soft-tissue trauma. Cases of this sort were major problems, and always a challenge to the skill and experience of the orthopedic surgeon. Treatment had to be highly individualized, and, depending upon the circumstances, might include sequestrectomy; saucerization and other techniques of resection; skin grafting; and bone replacement.
3. A low-grade infectious process might develop in several ways. It might follow the second variety of osteomyelitis just described if a split thickness skin graft was not replaced by full thickness skin coverage. It might occur when there was little bone damage but there had been extensive stripping of the periosteum, with extensive loss of overlying soft tissues. This category of osteomyelitis was sometimes necrotizing. All known principles of skin shifting and pedicle flaps had to be utilized to provide the necessary skin coverage. The cooperation of plastic and orthopedic surgeons was essential.

EVOLUTION OF CLINICAL POLICIES

The treatment of osteomyelitis early in World War II, no matter what the method and no matter how the fractures had been treated originally, was generally unsatisfactory. Not until the saucerization technique became standard did results improve. This technique was introduced by Maj. (later Lt. Col.) Robert P. Kelly, Jr., MC, at Ashford General Hospital, White Sulphur Springs, W. Va., in 1944, but it was not, as he was the first to point out, either a new procedure or original with him (*8–11*):

Lord recommended the management of cavities resulting from osteomyelitis by Thiersch's grafts in 1902 (*12*). In 1922, Reid published a comprehensive article on the use of large Reverdin's grafts in the healing of chronic osteomyelitis (*13*). Armstrong and Jarman contributed to the subject in 1936 (*14*), and Quick's 1943 report covered a 20-year experience (*15*). In 1942, Converse (*16*) published his work on skin grafting in war wounds. Regardless of the bacteriology and the apparent degree of contamination of the wound, he stated, the use of skin as a dressing often resulted not only in a considerable degree of "apparently non-specific benefit" in wound healing, but also in an impressively high proportion of takes. Parallel with the use of split thickness skin grafts in wounds was the development of pedicle grafts in osteomyelitis, the experience beginning with Neuber's report in 1896 (*17*) and going on to Lord's second report in 1935 (*18*) and Beekman's report in 1937 (*19*).

None of these methods came into general use with a single exception, the use of a shifting flap in indolent, persisting, or recurrent superficial ulceration involving epithelial tissue and underlying bone in old hematog-

enous osteomyelitis of the tibia. All scarred soft tissue and superficial unhealthy bone were excised, and, after a relaxing incision had been made, the intervening flap was undermined and shifted, to obtain per primam healing of the involved area. The former site of the shifted flap was filled in by a free skin graft.

Major Kelly had observed, and been impressed with, the procedure just outlined, as well as with the effectiveness of free skin grafts applied to granulating bone cavities after saucerization of infected bone. Converse's lecture on this technique at Walter Reed General Hospital, Washington, D.C., and his moving picture demonstration further convinced Major Kelly that grafts constituted the most efficient form of dressing in osteomyelitis. His opportunity to try out the technique came in January 1944, at Ashford General Hospital. The operation, carried out after cessation of drainage from an osteomyelitis of the middle third of the tibia, consisted of excision of the scar, saucerization, and skin grafting. Results were gratifying. The next (two) recorded procedures, performed by the same technique, were carried out in April 1944, though it is believed that other operations were performed in the interim and simply were not recorded. In both these recorded cases, the amount of drainage was "dramatically" reduced and wound healing was expedited. As time passed, this method was extended to other patients, and it finally came to be applied almost routinely at Ashford General Hospital whenever delayed primary wound closure promised to be difficult because of tension and dead space.

These circumstances were encountered rather frequently. Wound closure was seldom practical in patients with osteomyelitis received from overseas 5 to 12 weeks after wounding. At this time, there was usually considerable edema in the region of the wound, and the tissues were not pliable and did not take kindly to suture. Saucerization and skin grafting proved to be the answer to this problem.

There were, however, many occasions when it was difficult to make a sharp distinction between cases suitable for delayed primary wound closure and those that required skin grafting. When there was doubt, it became the general policy to employ skin grafting.

Results of this policy were particularly remarkable in several instances of osteomyelitis of the pelvic bones. In two such patients, a tube of skin extending deep into the pelvis permitted continued drainage in moderate amounts, improved the status of local tissues, and produced a notable improvement in the general well-being of both patients. Wound excision and closure had to be staged in both cases, but complete healing was confidently expected when they were last seen.

Another important consideration in these similar cases concerned surgical shock. In spite of aggressive preparation for operation, both patients just mentioned barely tolerated the procedure. Earlier surgery, without such preparation, would have constituted an intolerable insult.

Saucerization was a rational procedure. Radical excision of avascular

and infected tissue, obliteration of the resulting dead space, and wound closure produced all the factors necessary for prompt wound healing. The skin graft served, in effect, as a surgical dressing; it covered the defect with healthy, if thin, skin. Within a short time, dirty, draining, foul-smelling wounds were converted into clean, healed wounds. Loss of protein in the drainage fluid was stopped, and the patient's general condition improved in all respects, including the important factor of morale.

At this time, it sometimes seemed advantageous to delay further treatment, in the hope that the bone would now regenerate by natural process. If it did not, supplemental surgery could be carried out according to the indications of the individual case.

The introduction of saucerization and dermatome skin grafts, however, solved only part of the problem. Techniques had to be devised for further management of the clean wound. Delayed primary wound closure, full thickness skin grafts, and pedicle grafts were all useful, but there still remained a group of cases in which the condition of the bone furnished the major problem. The residual defect in the bone seriously impaired its strength, a matter of vital importance in the lower extremity, with its weight-bearing function.

A technique to correct this defect was devised at Crile General Hospital by Lt. Col. Marvin P. Knight, MC, and Maj. George O. Wood, MC, consisting of excision of the initial skin graft, obliteration of the bony cavity by bone chips, and application of a full-thickness skin graft (*7*).

As the war progressed, and after it ended, a tremendous backlog of battle casualties occupied the attention of plastic surgeons, which meant that they would not be available for the care of patients with osteomyelitis unless delays of months, or even years, were accepted. Of course, they could not be. Orthopedic surgeons, who understood the basic principles of skin transfer but who usually had had little training in its details, therefore, had to perform many plastic operations which otherwise would have been performed by plastic surgeons, or at least with their active cooperation.

The good results achieved by this technique (figs. 84 and 85) could not have been accomplished without (1) refinements in surgical methods; (2) the availability of plasma and whole blood; (3) the availability of antibiotic agents, which provided a protective barrier against invasive infection; and (4) the development of dermatomes, beginning with the Hood-Padgett instrument. The basis of success was twofold, complete excision of all diseased tissue and complete obliteration of all dead space.

ADMINISTRATIVE CONSIDERATIONS

When saucerization and skin grafting had proved their worth at Ashford General Hospital, Lt. Col. Robert L. Preston, MC, Consultant in Orthopedic Surgery, Fifth Service Command, used his efforts to introduce

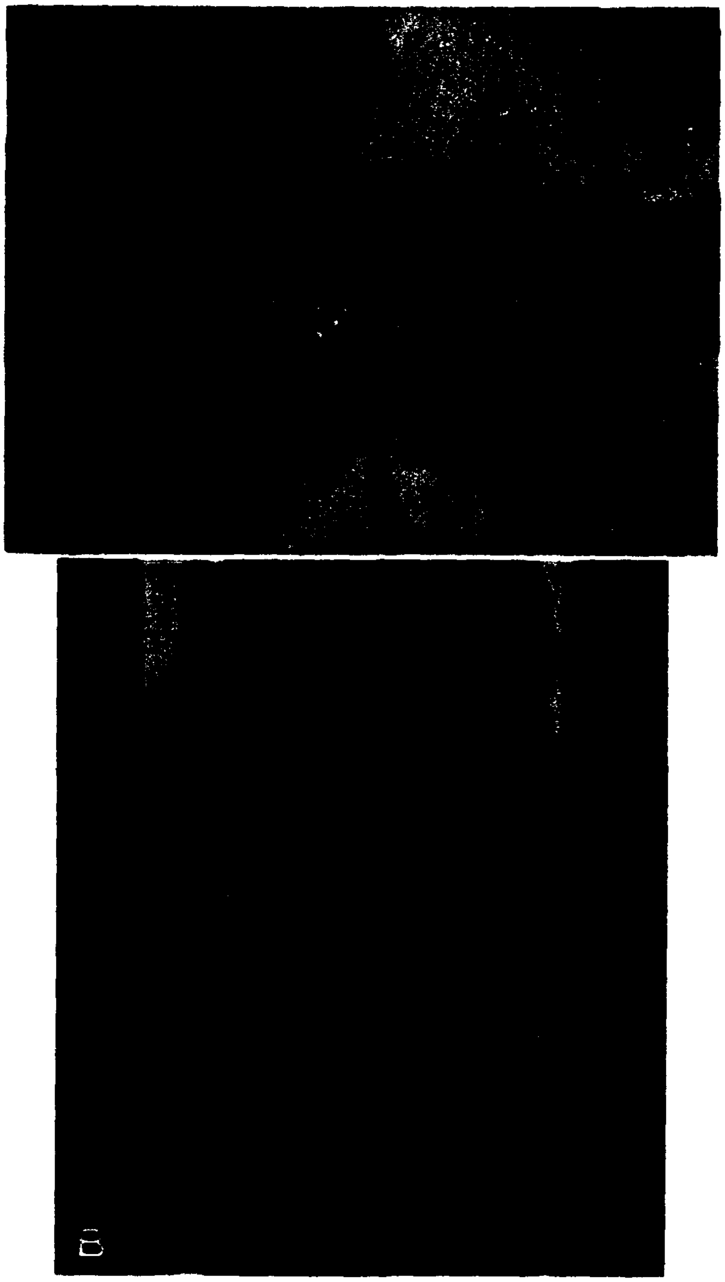

FIGURE 84.—Close-range bullet wound of right leg complicated by osteomyelitis and treated by saucerization and skin grafting. A. Clinical appearance of wound from medial aspect 2 months after injury, showing necrotic fragment of tibia, large sinus, and partial healing of skin defect by scar tissue. B. Anteroposterior and lateral roentgenograms of leg at same time, showing marked shattering of mid tibial shaft, with necrotic bone fragments and sequestra in depths of wound.

Figure 84.—Continued. C. Appearance of wound after saucerization performed in three stages over 6-week period, followed by peeling of granulations 3 days before this picture was taken, just before skin grafting. D. Split-thickness skin grafts sutured in place. Note that they fall of their own weight into the deep recesses of the wound.

the method at other hospitals in this command (*20*). In the meantime, Col. Claude S. Beck, MC, Consultant in Surgery in the same command, as soon as he had become aware of the work at Ashford General Hospital, introduced the technique into other hospitals as he visited them. Finally, at a meeting of the chiefs of surgery in the command, the new technique

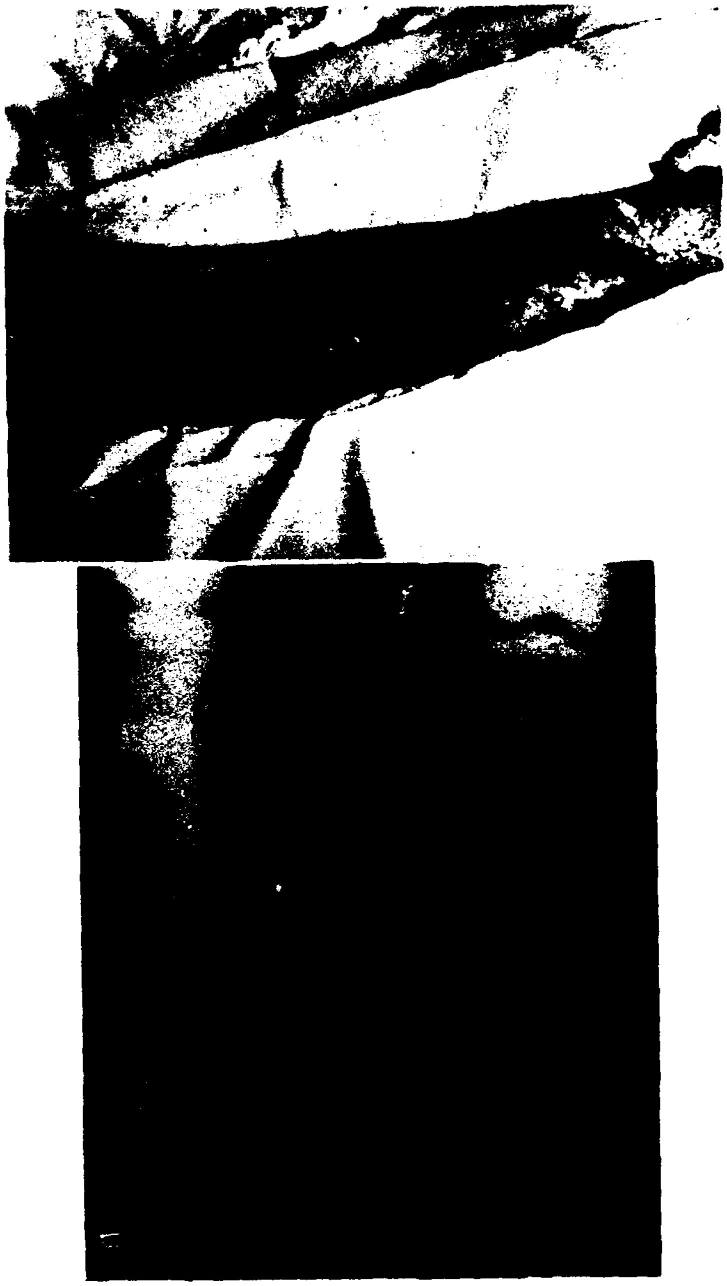

Figure 84.—Continued. E. Appearance of wound on removal of sutures 5 days after operation. F. Lateral and anteroposterior roentgenograms 20 days after operation, showing intact fibula and saucerized tibia. All sequestra and nonviable bone have been removed. (Kelly, R. P., Rosati, L. M., and Murray, R. A.: Ann. Surg. 122: 1–11, July 1945.)

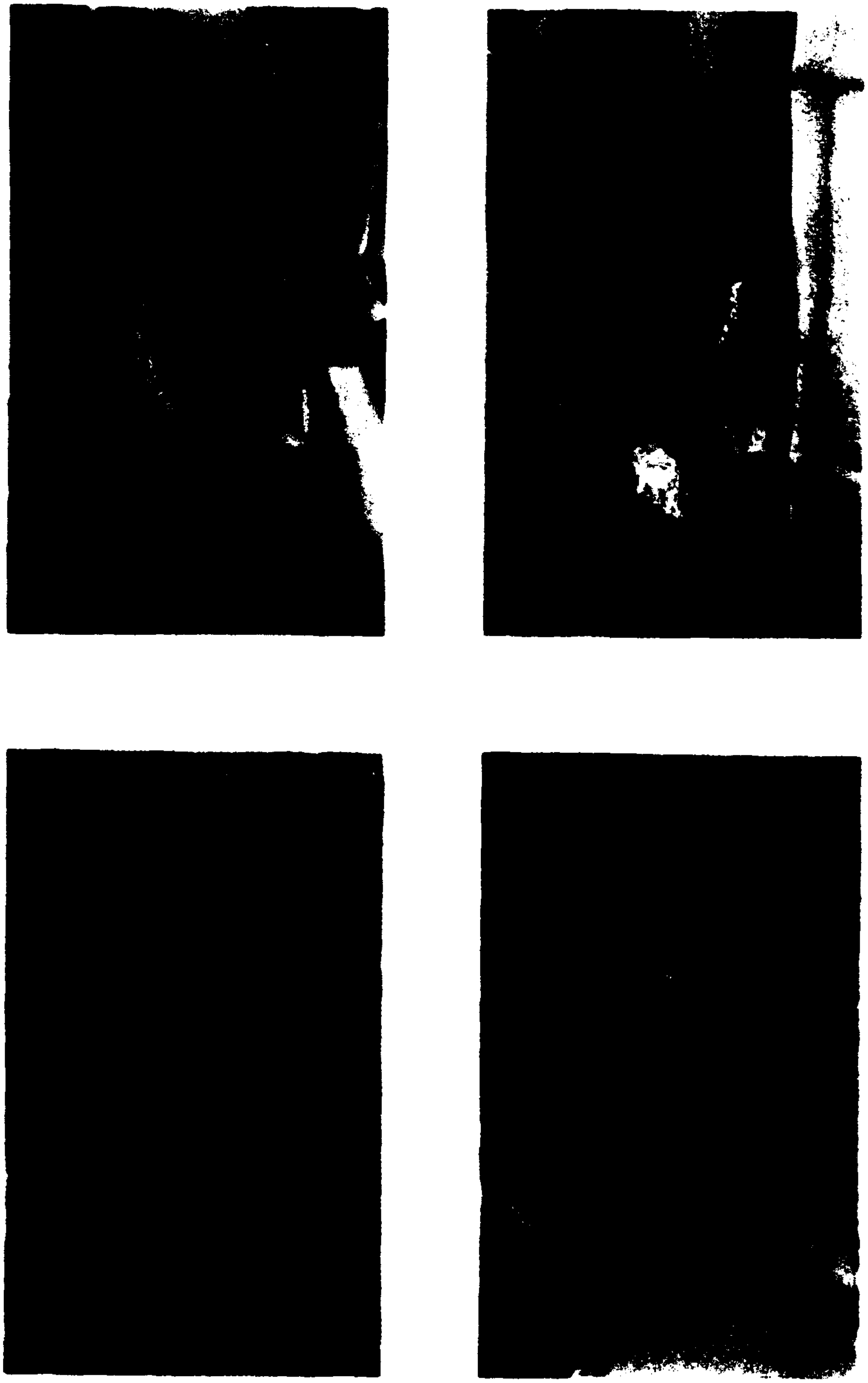

FIGURE 85.—Shell-fragment wound of right leg complicated by osteomyelitis and treated by saucerization and skin grafting. (Upper left) Appearance of wound 8 months after injury. (Upper right) Appearance of wound after saucerization. (Bottom left) Completed skin graft 4 days after final saucerization. (Bottom right) Wound almost completely healed.

was generally disseminated and its use, therefore, became general in command hospitals. Also, chiefly through the activities of the consultants in surgery and orthopedic surgery, it came into general use in other commands.

In January 1945, Capt. Ernest M. Burgess, MC, after a thorough training in the new technique at Ashford General Hospital, was sent to Billings General Hospital specifically to organize and direct the care of more than 400 casualties with active osteomyelitis (*4*). The hospital staff at this time consisted of four Board-certified orthopedic surgeons and several excellently trained general surgeons. Special wards were equipped for the care of these casualties. Ward officers devoted their entire time to them and were responsible for preoperative and postoperative care, both of which were extremely important in the new technique. The operating room was geared to run double shifts. The pathology laboratory cooperated. By June 1945, all but about 30 of these 400 patients had clean, well-healed, skin-covered wounds. About half had been treated by delayed primary wound closure and the others by skin grafts, in addition to saucerization.

Other hospitals sent medical officers on detached service to Billings General Hospital to learn the technique in use there. A monograph was prepared for their instruction.

The training and experience of orthopedic surgeons in World War II varied widely (p. 17), and there were not enough trained surgeons to handle the numbers of patients with osteomyelitis. General surgeons, both trained and untrained in that specialty, therefore, had to assume a considerable part of the responsibility. At Billings General Hospital, during the period the largest number of casualties with osteomyelitis were under treatment, the orthopedic section had no chief, but was directed by Colonel Rice, Chief of Surgery (*2*).

The value of the consultant system in the dissemination of information is evident in what has just been said about osteomyelitis. Sometimes, however, there were obstacles in the way. When the Consultant in Surgery, Fifth Service Command, tried to arrange for a meeting of service command orthopedic and other surgeons, to demonstrate the technique which he had observed, with warm approval, at Ashford General Hospital, he had difficulty in persuading the Command Surgeon that osteomyelitis was a sufficiently important complication to warrant such a gathering. The only way, in fact, that the Consultant in Surgery was able to spread the information was by slipping it onto the program of a conference on the urologic complications of paraplegia held at Newton D. Baker General Hospital, Martinsburg, W. Va., in May 1945.

TIMING OF SURGERY

Basic surgery.—The timing of surgery for patients with osteomyelitis was a matter of debate. Many orthopedic surgeons believed that a minimum

delay of 3 months was necessary after cessation of all drainage before definitive soft-tissue repair should be undertaken and that a minimum of 6 months should elapse before reconstruction. Shorter periods, they believed, invited recurrent infection. Even after penicillin became available, many surgeons were unwilling to risk postoperative flareups by undertaking surgery too early. Delay was the policy in civilian life, and it was carried over into military practice.

There was a good deal of evidence in favor of this conservative point of view. In 73 healed cases, for instance, treated at Vaughan General Hospital, Hines, Ill., the most rapid healing, 10 days, occurred in patients who had had the longest preoperative delay, averaging 6.5 months (*21*). The surgeons at this hospital considered it a specious argument that a preoperative delay of 2 months, with a postoperative drainage period of 4 months, could be equated with a preoperative period of 4 months and postoperative drainage for 2 months. Along with shortened postoperative drainage periods went other benefits, including less scarring, more adequate delimitation of bone infection, easier definition of bone at operation, less sacrifice of bone, increased chances of firm bony union, and fewer residual defects.

Although there might be differences of opinion concerning the length of time delay should be practiced, the majority of orthopedic surgeons were opposed to early surgery. Among those who held the opposite point of view was the distinguished orthopedic surgeon, Dr. Marius N. Smith-Petersen, a special consultant to The Surgeon General. In December 1944, in visits to Cushing (Framingham, Mass.) and Lovell (Ayers, Mass.) General Hospitals, he expressed the opinion that the delays being practiced before surgery in osteomyelitis were unnecessary because of the availability of penicillin. He thought that open reduction, osteotomy, and bone grafting could be carried out without risk of recurrent infection before wound healing. He was willing to do reconstructive work on bones even in the presence of open granulating wounds, though in the presence of purulent discharges or sequestra, he would delay surgery until healthy granulations were established.

Dr. Smith-Petersen also called attention to a serious risk of delayed surgery: In spite of physical therapy and careful joint motion, muscle and joint changes were likely to occur before repair could be consummated.

Lt. Col. (later Col.) Condict W. Cutler, Jr., MC, Consultant in Surgery, First Service Command, reported these recommendations to the Surgeon General's Office, at the same time expressing his own fears of a situation in which dead space or potential dead space was left in an infected wound and in which foreign bodies (Smith-Petersen cannulas) were introduced into the wound (*22*). The Consultant in Orthopedic Surgery, Surgeon General's Office, was not enthusiastic about the radical approach just outlined, but was willing that it be tried in certain selected osteotomies and arthrodeses. His own preference, like Colonel Cutler's, was for delayed

primary wound closure or skin grafts, with proper timing. It was agreed that dermatome grafts might perhaps be applied a little earlier in infected wounds that had healed without complications, but that great caution should be exercised in performing bone grafts and other radical surgery in infected fields.

At Billings General Hospital, the original policy was to wait an arbitrary 3 months after complete wound healing before attempting further plastic or bone surgery (*4*). An analysis of the early material, however, showed that about 60 percent of the wounds which broke down after repair could be explained by aseptic (avascular) necrosis and were the result of sclerosis of underlying bone. Another 10 to 15 percent of breakdowns could be explained by leakage of synovial fluid in joint injuries in which ablation of the joint surface had been omitted.

These observations convinced the orthopedic staff that many resaucerizations might have been avoided if it had been recognized that, in many instances, the cause of the breakdown of the skin graft was in fact avascular, not infectious, and that additional surgery could safely have been carried out earlier. The policy was, therefore, altered: When sclerosis was recognized at the end of 3 months, formal bone grafting and reestablishment of medullary continuity were undertaken without further delay. Still later, in the belief that sufficient healing had taken place without infection within 3 to 4 weeks after skin grafting to make bone grafting safe, skin tubes were prepared for wound coverage and bone work was carried out promptly, with the expectation that the extent of sclerosis beneath the dermatome graft would thus be reduced.

Surgery secondary to saucerization and skin grafting.—At Ashford General Hospital, the original policy was to wait for periods up to a month between saucerization and skin grafting (*8, 11*). This interval was progressively shortened to 3 or 4 days. The final decision was that the optimum range was relatively narrow, not usually earlier than the fourth day (though in a few cases at both Ashford and Billings General Hospitals, the graft was applied at the saucerization operation, with good results) and not later than the 11th day. If the graft was applied too early, its death was likely because of inadequate vascularization of the bony base. Moreover, granulations developing in less than 4 days were usually too inconspicuous to permit ready differentiation between vital tissues and tissues that were necrotic or partially necrotic and of such low vitality that they would not sustain a graft. Uniformly healthy granulations, however thin, that were visible after 4 days' use of pressure dressings were an index of a healthy wound and likely to react favorably to skin grafting.

If grafting was delayed too long, a heavy overgrowth of dense, infected, superficially edematous granulation tissue would imperil the take. Generally speaking, results improved as the period of delay between saucerization and grafting was shortened. Some surgeons thought that longer intervals had no adverse effects, but this was not the general opinion.

Aside from the original lack of experience, which required trial-and-error timing, delays in grafting were explained by such causes as the long duration of osteomyelitis before operation and the degree of osteosclerosis about the fracture site at the time of the primary operation.

SAUCERIZATION

Preoperative Management

Saucerization in osteomyelitis was major surgery, which required intensive preoperative preparation and postoperative care.

Preoperative preparation, the components of which are outlined elsewhere (p. 441), varied in details from hospital to hospital, but, in general, was basically the same everywhere. It began with an evaluation of the patient's general condition. Plasma or whole blood, high-protein, a high-vitamin diet, and other supportive therapy were instituted as indicated.

The local pathologic process was investigated clinically, by routine roentgenologic studies, and then by Lipiodol visualization, with stereoscopic views to show the extent and ramifications of any sinus tracts present.

If edema was part of the picture, the limb was kept elevated. Some hospitals practiced exposure of the wound, to improve the condition of the soft tissues, which were often inflamed and macerated from prolonged contact with drainage fluids. The patients were, however, kept ambulatory whenever that was possible. Nonunions in the lower extremity were protected by non-weight-bearing calipers, and the patients were put through a formal routine of ambulation to combat the extreme osteoporosis present in many instances.

Preoperative physical therapy consisted of active assisted exercises of the affected extremity, with local massage to improve the circulation and increase muscle tone. The majority of patients had some fixation of neighboring joints, especially when the upper extremity was involved. When possible, they carried out active exercises every hour with other ward patients.

In a symposium on bone grafting, Lt. Col. (later Col.) Robert H. Kennedy, MC, Consultant in Surgery, Second Service Command, emphasized the importance of maintaining the axis and length of an extremity with a large bone defect during the healing process (*23*). Carelessness in this regard, which was not infrequent, made reconstruction more difficult. If traction was properly employed, both axis and length could be maintained, and the later problem would be limited to filling in a partial defect rather than grafting a completely mobile bone.

The general principles of preoperative management just outlined were also applicable, in large part, to bone grafts.

Technical Considerations

Saucerization was not regarded as a particularly good word for the procedure it was intended to describe, but, like many other medical terms, it continued to be used because it had been used. To Colonel Kelly, it implied that all devitalized tissue was removed at operation and that the contour of the resulting wound was such that a skin graft, over which appropriate pressure could be maintained, could be applied to it (*8*). To the surgeons at Vaughan General Hospital, the term implied that the creation of a saucerlike topography necessitated the sacrifice of adjacent normal bone and exaggeration of preexistent defects (*21*). The point to be remembered in all saucerization procedures was that they were preparatory, not definitive, operations, designed to prepare the ground for the skin grafting that was the ultimate goal of the procedure.[2]

Ashford General Hospital technique.—The incision for saucerization was begun at the point of juncture of healthy and unhealthy skin. A line of cleavage was developed between scar tissue and the relatively normal surrounding tissue; it was followed down on one side to the depth of the wound and thence up the other side to the opposite edge. This technique permitted complete en bloc removal of all unhealthy tissue and all foreign bodies. If total removal was not accomplished by it, residual unhealthy tissue and foreign bodies were excised. If skin edges which had appeared healthy along the line of excision were found fibrosed and scarred on the undersurface of the involved tissue, they were excised and the skin was mobilized back to healthy soft tissue. Any remaining skin whose vitality seemed questionable because of cyanosis or ischemia was also excised.

Shaping of the wound to the topography desired for skin grafting was then carried out. In the course of this step, any small sequestra and foreign bodies that were encountered were removed. Next came the removal of any tissue which, though not frankly scarred, appeared of low vitality and in the surgeon's opinion would have little, if any, functional value. If denuded tendons or ligaments were considered vital to function, an attempt was made to cover them by shifting flaps of local healthy skin. If this maneuver was impossible, they were excised and subsequent reconstructive surgery was planned.

Every care was taken, of course, to preserve the integrity of nerves and major blood vessels at operation, and periosteal stripping was kept to a minimum. Resection of bone was carried to such a point that the surgically created weakness did not exceed that of the preexisting weakest link caused by the original pathologic process. This principle was violated only when the functionally essential stability of the skeletal structure would not be disturbed or when the violation was necessary to permit access to devitalized tissue.

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[2] In reality, saucerization is simply a second debridement.—M. C.

The technique described was developed by trial and error. Once it was developed, it was adhered to rather rigidly. It was analogous in its principles to debridement of a fresh wound, with the additional requirement that the wound must approach a saucer shape. If this objective was met sufficiently to permit a satisfactory pressure dressing to be applied over the skin graft that constituted the second step of the procedure, then no additional healthy soft tissue had to be sacrificed.

Billings General Hospital technique (*2, 4*).—Orthopedic surgeons at Billings General Hospital were constantly reminded that the defect they were creating must be covered with skin and that depth of the wound was not in itself a hazard. Grafting was carried out successfully in wounds that descended vertically 4 inches or more through soft tissues down to bone. Overhanging wound edges, crevices, small, pencil-like tracts, and sharply wedged angles were avoided. If the infectious process involved the shaft of a long bone and a plug of intramedullary scar had formed a barrier to its further extension, the plug usually was not removed completely, for fear of creating a defect that would be mechanically unsatisfactory for reception of a skin graft. The less the residual scar, the more vascular the wound and the more complete and the more rapid the healing of the wound.

If a small bridge of skin and soft tissue lay between two major draining areas that communicated with each other, it was sacrificed if it was small. If the bridge was large enough to justify salvage, it was converted into a double-end flap and sutured over one of the defects, leaving the other to be skin-grafted. Plastic procedures and partial wound closure were not recommended at saucerization.

Through-and-through wounds presented particularly difficult problems. They were occasionally tunnel-grafted successfully after saucerization, but the best plan was to wait until some tissue had built up between the wounds and then handle each one separately by saucerization and skin grafting.

In the management of involved joint surfaces, all residual cartilage was removed until bleeding, healthy, subchondral bone was exposed. Bone that was clinically viable, from which periosteum and soft tissues had been removed, could be drilled to stimulate surface vascularity. The more usual practice was to remove a portion of the external cortex with a sharp osteotome. A dense osseous base was left, but if surgical timing was correct, skin grafting was usually successful.

In some cases, saucerization had to be accomplished in stages. When this was necessary, granulations developing in the area untouched after the first operation sometimes became thick and edematous. In such cases, after a delay of 2 or 3 weeks, the granulations were peeled from the wound as a final preliminary procedure. Thereafter, the wound was treated as if only a single saucerization had been necessary.

Postoperative Measures

When saucerization was first employed at Ashford General Hospital, an orthodox Orr dressing was used after operation. Later, this dressing was discarded for two reasons: Fatty substances on the granulating bed were thought to interfere with vascularization of the graft, and thick, edematous granulations had the same effect. Instead of the Orr dressing, therefore, a layer of fine-mesh gauze, made as wrinkle-free as possible, was placed in direct contact with the wound, and over it was placed a suitable mass of mechanics' waste. An elastic bandage was then so applied as to provide as much pressure as possible to the wound without embarrassing the circulation at the more distal points. Circulatory risk could be reduced by extending the area over which pressure was made to the base of the toes or the fingers. To permit swelling with minimal increase in pressure, a thick layer of sheet wadding was wrapped over the elastic bandage, after which plaster immobilization was applied, as in the standard Orr technique. Packing was an important adjunct in the stimulation of growth of a healthy granulation tissue base. When there was a delay of several days between removal of the packing and skin grafting, the rapid growth and weeping that occurred in the granulation tissue after the release of pressure resulted in considerable deterioration of the wound. Unless, therefore, there was sound reason for delay, the skin graft was always applied not later than the day after removal of the pressure dressing.

Later in the experience at Ashford General Hospital, a single Carrel tube was incorporated into the mechanics' waste and brought out through the encasement. It was found that irrigations with 1-percent acetic acid every 4 hours, in amounts proportionate to the size of the wound, reduced the incidence of contamination by *Bacillus pyocyaneus* and *Bacillus proteus*. At Billings General Hospital, the wound was irrigated with physiologic salt solution and packed with strips of gauze saturated with it before the pressure dressing was applied. The extremity was kept continuously elevated.

In the occasional case in which bleeding of any consequence occurred, a window was cut into the cast and the packing was reinforced with additional pressure. In all such cases, the oozing was general and was readily controlled.

Otherwise, the standard postoperative regimen for orthopedic surgery was instituted.

SKIN GRAFTING

Technical Considerations

The timing of skin grafting in relation to saucerization has been discussed earlier in this chapter. Immediate local preparation consisted of

bivalving the plaster encasement before the patient went to the operating room, followed by the usual orthopedic preparation and the preparation of donor sites. At Billings General Hospital, in a few cases in which it was necessary to maintain stability during operation, the procedure was carried out through a window in the cast.

When the wound was inspected, if it did not look clinically clean, saucerization was repeated. In a few cases at Billings General Hospital, saucerization was performed three times, at weekly intervals. The decision as to the fitness of the wound for skin grafting was made only on the gross appearance. Other factors being equal, the results were related to the status of the wound bed when the graft was applied.

Grafts were obtained from the most convenient source, usually the thigh, abdomen, back, or chest. By the use of the Padgett's dermatome, grafts of predetermined thickness (usually 0.014 to 0.018 of an inch) could be obtained in sufficient quantity to cover the largest saucerized areas. Three or four drums of skin were sometimes required for adequate coverage.

Thinner grafts were found to heal more rapidly than thicker grafts and generally were preferred by surgeons who worked on the principle that all free grafts should be replaced. Thicker grafts were likely to be associated with considerable sloughing, which prolonged the postoperative period, though, once the sloughing process was complete, excellent coverage was usually attained, and a large proportion of the surfaces of the graft was found to contain skin accessories. Lessened surface necrosis led to prompter completion of secondary epithelization and saved time and trouble for the surgeons.

The contour of the wound to be grafted introduced certain problems. On a flat surface, a skin graft could be subjected to some tension without reducing the possibility of applying uniform pressure of suitable degree over the wound. On the uneven, and often complex, surfaces of saucerized wounds, it was necessary to eliminate all tension from the graft to attain the ideal of uniform pressure at all points. Wrinkling also had to be avoided. By a careful technique, with removal of V-shaped pieces of skin at strategic points about the graft, it was practically always possible to accomplish a patchwork fitting of the wound surfaces. At one hospital, good results were obtained with grafts cut into ribbons, but most surgeons preferred grafts cut in a single piece and tailored to fit the wounds.

After skin for the graft had been secured, the donor site was covered with a single layer of gauze impregnated with boric acid ointment and overlaid with sterile dressings. At Crile General Hospital, the epithelial surface was lightly dusted with sterile powder to prevent its adherence to the dressing. Great care was taken to avoid cross contamination.

The recipient area was prepared for application of the graft by curettage, with removal of all tissues that were sloughing, edematous, or avascular. The graft was then shaped into an irregular, blunt cone and applied to the depressed saucerized area. The margins of the graft were sutured

to the skin edges. Untied running sutures, with one end left long, were placed along the secondary suture lines necessitated by the complicated fitting of the graft. These sutures were withdrawn when the graft had become firmly attached to its bed. A sutureless technique was not considered practical for wounds of such depth and irregularity.

When the open medullary cavity presented at one end of the depth of the saucerized wound, a gap of small diameter might exist in the granulating bed at this point. A vertical slit in the portion of the graft overlying the gap provided for contact with the bed, on the presumption that delayed filling of the gap by granulation would follow and secondary epithelization would finally effect closure.

At some hospitals, a single layer of boric acid ointment-impregnated gauze was laid over the wound. At others, this step was omitted. Mechanics' waste was packed into the cavity, from the depths outward, the greatest care being taken to fill all recesses completely and snugly. It was most important to institute and maintain accurate, firm, uniform pressure over every area of the wound, to insure intimate contact between the graft and the recipient area. Dry dressings were placed over the waste, and an elastic bandage was then applied. Immobilization was accomplished by a splint or cast.

When saucerization and skin grafting were first used at Billings General Hospital, the grafts were molded over dental cement or paraffin, which was placed in the wound and removed after it had hardened. It was soon found that accurate tailoring of the graft could be better accomplished by its direct application to the wound. A technique that involved the use of an inflatable rubber bag to accomplish pressure, devised by Maj. William A. Antopol, MC, at this hospital, did not progress far enough during the war to permit clinical appraisal (*2*).

Postoperative Management

In the postoperative period, the extremity was kept continuously elevated, and was frequently observed, to detect possible circulatory embarrassment without delay. Otherw se, the usual orthopedic regimen was instituted, including antibiotic therapy. Some hospitals used local irrigations of penicillin solution, especially when there was considerable drainage.

The pressure dressings were removed as early as possible, to prevent loss of the graft by maceration. At Ashford General Hospital, it was found that they could safely be removed on the fourth day, but 6 days was considered optimum. This period was also the preference at other hospitals. By this time, from 80 to 95 percent of the graft usually had taken, and it was not unusual to find the entire wound surface completely covered with epithelium. After the dressings were removed, gauze compresses were loosely inserted into the wound and kept moist with a saturated solution

of boric acid. If culture showed the organisms present to be penicillin-sensitive, penicillin solution was substituted for the boric acid solution unless *B. proteus* or *B. pyocyaneus* was present; in that event, 1-percent acetic acid solution was used. During this period, the graft was left exposed as much as possible, since maceration was a hazard until all drainage had ceased. The routine described was continued until complete epithelization had occurred.

At Billings General Hospital, a heat lamp was used two or three times daily if the graft was moist. Cleansing of crusts and other local measures were carried out as indicated, to stimulate healing. Patients were allowed out of bed only for short periods of time, and moderate elevation of the limb was continued during recumbency, so as not to alter the circulatory status during the early weeks of healing.

At this hospital, 25 days after the application of the skin graft, the wound was evaluated by the staff. On the 50th day (also selected arbitrarily), the wound was again evaluated. Any wound that was not completely dry, healed, and covered with skin at this time was listed as a failure, even though it was realized that it might subsequently progress to complete healing. Moderate blistering or occasional areas of moisture over the surface were not considered abnormal.

DEFINITIVE SURGERY

Healing after skin grafting raised the question of what to do next—institute no further treatment or carry out procedures to replace the free skin graft?

When the free-grafted surface was flat, success practically always followed plastic surgery performed according to accepted principles. There was, however, an admitted risk in leaving free skin grafts in situ, particularly those over areas of friction: Their vitality was continuously threatened. Congestion, with capillary extravasation and edema, favored activation of latent infections. Impaired venous return, whether temporary or permanent, was the rule when ambulation was resumed. Split-thickness grafts, depleted of accessory organs, were highly sensitive to all irritants, including dirt, which has an irritant effect even on normal skin. Such grafts were prone to maceration and smegma-formation because in saucerized wounds, they were poorly aerated. No matter what the patient's zeal for cleanliness, unfavorable hygiene was unavoidable because the grafts were largely inaccessible. The thinner the graft and the poorer the initial take, the greater was the trend to deterioration. Some patients whose saucerization and grafting were originally successful later developed small areas of ulceration while on long furloughs; some of these areas healed with bed rest, but additional surgery was necessary in others (*8*).

In short, as was said originally, nonreplacement of a split-thickness graft was always attended with risk. Replacement was, therefore, the

FIGURE 86.—Closed pedicle skin graft from abdominal wall created to cover extensive skin defect of lower posterolateral humeral and elbow regions of left arm. (Kelly, R. P., Rosati, L. M., and Murray, R. A.: Ann. Surg. 122: 1–11, July 1945.)

general practice. It could be accomplished by excision of the graft and closure of the adjacent tissues (local closure), pedicle grafts, or obliteration of the saucerized cavity by bone.

Local Closure

Local closure, which meant excision of the graft and closure of the adjoining tissues, was the more likely to be successful the greater was the ratio of soft tissue to bone involvement and the less the ratio of width of the original wound to the circumference of the part involved. Superficial closure was usually only a minor problem, particularly when relaxing incisions were used. It was a major problem when local closure was planned to obliterate deep dead space resulting from bone and soft tissue loss. Unless this space was obliterated, however, success could not be expected.

Pedicle Grafts

Pedicle grafts from the abdomen.—Pedicle grafts, secured from the abdomen (fig. 86), were extremely satisfactory in the management of defects of the upper arm and the forearm (*8*). Most defects in the abdominal skin left after transfer of the flaps could be closed simply by undermining and approximating the skin edges.

Larger, more complicated flaps had to be planned well in advance of the need for them. Stockinet patterns, cut in the shape of, and slightly larger than, the area to be covered, and with wide pedicles, could be strapped to the abdomen with adhesive in various locations. Thus, it was possible to assure, in advance of the need, an abundant blood supply at the base of the pedicle, a comfortable and readily maintained position of the arm during transfer of the flap, and a pedicle free of abrupt kinks and twists.

If the pedicle was relatively wide, the flap could be based in any direction. The wider the base of the flap in proportion to its length, the greater were the chances of success. The limit of safety for a flap to be raised and applied in a single stage was in the range of two units of length to one unit of width of the pedicle base. When the base included epigastric vessels, this ratio could be somewhat exceeded. It was wise to proceed slowly, watching for the danger sign of cyanosis of the skin edges. If this sign appeared before the flap was completely elevated, a delay of a week was indicated. A corollary to this observation was that the area to be resurfaced should not be denuded until one was certain of a flap that could be transferred.

Adhesive strapping was a satisfactory immobilizing agent for most abdominal pedicle flaps. It had to be applied carefully, to discourage maceration and permit frequent dressings.

Cross-leg pedicle flaps.—At Ashford General Hospital, cross-leg pedicle flaps were created by the Ghormley-Lipscomb technique (*24*). Again, advance planning was important. After a preliminary outline had been made down to the deep fascia by parallel incisions, followed by almost complete undermining a week later, a dermatome graft was placed beneath the pedicle at the end of another week. Some fibrosis occurred, but no other deleterious effect was apparent on the deep surface of the overlying pedicle. Takes were usually excellent (fig. 87). The fibrotic area was resected when the flap was applied, but this step would be necessary in any flap undermined before it was applied. It was a considerable advantage to have the donor site already surfaced with skin when the pedicle was transferred. The end of the flap to be transferred was partially severed a week after the dermatome graft was applied. A few days later, it was completely severed and applied to its intended destination.

To avoid abrupt kinking and twisting of the cross-leg pedicle, it was sometimes desirable to outline the flap obliquely, or even to base it distally instead of proximally. The farther the axis of the pedicle deviated from the normal direction of blood flow in the extremity, the greater the care necessary to develop the pedicle. When the cross-leg flap was bizarrely based or directed, partial severance was best carried out in two or more stages before the initial application.

Just before the initial application of the pedicle, the legs were placed in the desired position and the position of the joints was noted. Plaster

FIGURE 87.—Combat wound of right leg complicated by osteomyelitis and treated by cross-leg pedicle skin graft. (Top) Open pedicle cross-leg skin graft from lower left leg, based distally, used to replace split-thickness skin grafts over large defect of right lower leg. (Bottom) Appearance of legs with recipient site on right leg fully healed and donor site on left leg also completely healed after application of split-thickness skin grafts. (Kelly, R. P., Rosati, L. M., and Murray, R. A.: Ann. Surg. 122: 1–11, July 1945.)

immobilization was then applied to each leg separately. Ample windows were cut to expose the pedicle and the area to be resurfaced. After the

pedicle had been transferred to its new site, braces were placed between the plaster casts, to stabilize the legs.

Care was taken to avoid any tension on the pedicle. Whenever it was practical, the graft was observed for circulatory changes at 2 hours, and again at 24 hours, after operation. In a few instances, immediate detection of circulatory difficulties permitted the immediate return of the pedicle to its previous site.

The technique just described was practical if the contours of the skin-grafted area presented no potential dead space. The presence of such space made successful replacement of a dermatome graft by a pedicled transplant almost impossible. Localized pressure or localized tension sutures intended to force the pedicle into the dead space jeopardized the circulation of its distal points. To avoid this risk, cavities had to be eliminated by some means which did not offer intolerable insults to the tissues.

Tubed Pedicles

After bone replacement failed at Ashford General Hospital, attention was directed to the use of abdominal tubed flaps (*8*). The fat tissue was inverted into the cavity by various techniques, the blood supply being maintained intact. The greatest limitation of tubed pedicles was that they were not practical for cavities that were excessively large and steep. Though the 2 : 1 ratio of length to width could be slightly exceeded with safety in most tubes, there was little to be gained by exceeding it. A better plan was to extend the pedicle either by further tubing of the skin or by so-called paddling. At the end of 2 weeks, the end of the tube was pinched off for increasingly long periods until the occlusion could exist for half an hour with minimal circulatory changes.

Most of the difficulties experienced with tubed pedicles at Ashford General Hospital occurred in a phase of management in which orthopedic surgeons should have been entirely at home; namely, immobilization. When the tube was transferred, the suture line had to be protected from tension and excess mobility, and the entire tube had to be protected from kinking. These precautions were sometimes overlooked.

During the transfer of a tube to the wrist, a plaster body jacket was used to fix the shoulders and hips. The jacket was joined by braces to a plaster which maintained the wrist in cockup position and the elbow in as much flexion as the position of the tube permitted. The angle of approach of the tube to the wrist, which at this stage was controllable, had to be planned to minimize kinking at the next stage. It was also essential to plan the eventual position of the suture line, so that the tube would not be subjected to torsion when it was transferred. The window in the plaster through which the tube passed to the suture line at the wrist had to be ample enough to avoid any impingement on the tube. For the same reason,

the extremity had to be fixed firmly in the plaster by dorsiflexion of the hand and flexion of the forearm.

These principles of immobilization had to be adapted to the successive stages of the transplantation of the tube and had to be strictly observed.

Methyl Acrylate Molds

In 1945, Capt. Edmond R. Zaglio, MC, Ashford General Hospital, began to use methyl acrylate molds on saucerization cavities (*11*). They were prepared, in advance of surgery, from dental compound models (fig. 88). The work was begun too late in the war for any conclusive results to be obtained, but, like many other accounts included in this volume, it is part of the wartime history of orthopedic surgery in the Zone of Interior and is included for that reason.

One advantage of this technique over the use of bone grafts (which were a dismal failure at this hospital) was that methyl acrylate is relatively inert and molds, therefore, could be left in situ indefinitely.

In one of the first four cases handled with these molds, healing occurred promptly and per primam in a clean wound. In the other three, previous attempts to replace dermatome grafts had failed:

Case 1.—In this case, the mold overlay a completely ankylosed hip. The patient was afebrile after the second postoperative day. Satisfactory closure of the wound was effected and the small amount of drainage present when he was last seen was of superficial origin. It was planned to leave the mold in place.

Case 2.—This patient's wound was still draining 4 weeks after replacement, by iliac bone chips, of a skin-grafted tunnel through the upper third of the tibia and very successful tubed graft coverage of both skin ends of the tunnel. When the infected chips were removed, a halved mold of the tunnel was prepared, and 2 days later, after the use of pressure dressings in the interim, the mold was placed in the wound and the flaps were loosely closed. Healing was complete in 2½ weeks. Streptomycin was given after culture of the drainage fluid revealed *B. proteus.*

Case 3.—The acrylic mold in this case was designed to fill deep dead space by bone cavitation. Only the tissues over the mold were closed when it was inserted, for fear of spreading *B. proteus* infection, with activation of latent *S. aureus* infection after inactivation of penicillin. Four days later, when induration and other local signs of wound inflammation had greatly decreased, delayed primary wound closure was completed. A small space in the center of the wound was left open. Healing was almost complete at the end of 3 weeks.

Bone Replacement

Ashford General Hospital.—For some reason, the attempt at Ashford General Hospital to fill bone cavities resulting from osteomyelitis with bone resulted in only two successes in 11 trials. The method was, therefore, abandoned (*9*). Better results were secured elsewhere, Crile and DeWitt General Hospitals serving as illustrations:

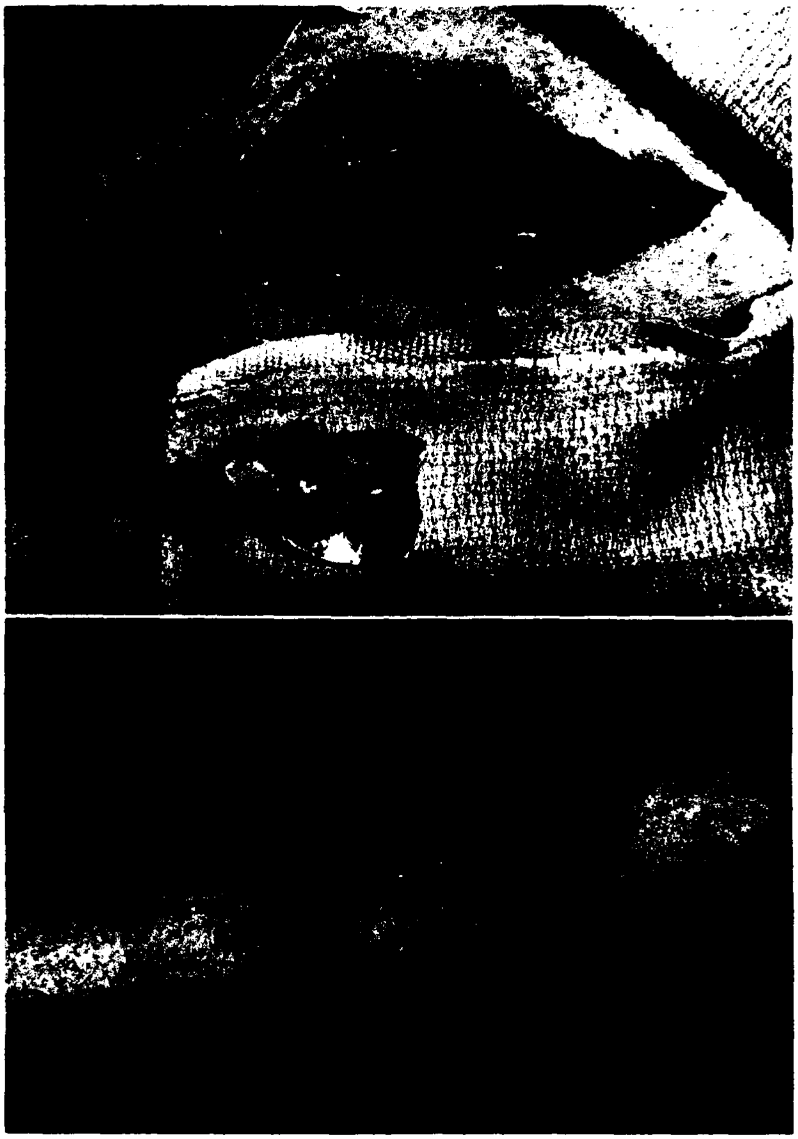

Figure 88.—Combat wound of right leg complicated by osteomyelitis and treated by skin grafting and methyl acrylate mold. (Top) Appearance of wound after excision of skin graft. Note mold ready for insertion. (Bottom) Appearance of wound 9 days after insertion of mold and closure of locally available skin over it. (Kelly, R. P., Rosati, L. M., and Murray, R. A.: Ann. Surg. 122: 1–11, July 1945.)

Crile General Hospital.—At Crile General Hospital, bone replacement of saucerized cavities was carried out as follows (*7*):

1. Suitable full-thickness coverage of the defect had to be assured before any other steps were taken at operation. It was frequently possible to undercut the margins of the skin adjacent to the cavity, so that viable full-thickness skin could be closed over the cavity without tension. Whenever possible, closure was so planned that the

suture line did not overlie the cavity. To achieve this purpose, it was frequently necessary to elevate a double-pedicle sliding flap in the area adjacent to the cavity on one side and then to shift the flap in order to place the suture line as desired. The creation and shifting of these flaps presented no problems if the ratio of length to width did not exceed 3 : 1. In an occasional case, it was necessary to raise flaps on each aspect of the wound. Very occasionally, after a flap was elevated, its circulation did not seem adequate and it was necessary to return it to its bed and delay further surgery for 2 or 3 weeks. The pedicle technique was required in a few cases in which there had been extensive loss of soft tissue.

2. Whatever the method, it was imperative that skin flaps be prepared and be tested over the cavity before any other step was taken. When proper coverage had been assured, the split-thickness lining of the saucerized area was excised. The medullary canals of both fragments were reopened and the bony surfaces were scarified throughout.

3. Autogenous bone chips were procured from any convenient source (the wing of the ilium was excellent) in quantities sufficient to fill the cavity, and the prepared flap (flaps) was shifted over them. A split-thickness graft, obtained from the thigh, was utilized to cover the denuded area representing the former location of the pedicle flap.

4. As soon as the sutures were removed, the extremity was immobilized in plaster.

DeWitt General Hospital.—The first patient treated by the bone replacement technique at DeWitt General Hospital, in June 1944, had a large, purulent chronic focus of osteomyelitis in the upper tibia, for which radical resection was necessary (*6*). Postoperative measures included local instillations of penicillin in addition to its systemic administration. On the eighth day, the entire bony defect was covered with thin but healthy, velvety-appearing granulations. Pedicle techniques of replacement were not considered suitable in this case, and with recollection of Abbott's demonstration of the value of cancellous bone in such circumstances (p. 407), it was decided to fill the cavity with bone secured from the ilium.

In this case, as well as in a second case similarly treated, large pieces of ilium, including the cortex, were used, with only indifferent success. Suppuration continued in both cases. When the wounds were examined, it was noted that the cancellous portion of the implanted bone bled freely, and had apparently become revascularized; it was the cortical portion which was suppurating. It was, therefore, decided that for the future, only small, cancellous chips of ilium, from which all cortical elements had been removed, would be utilized in bony cavities.

Timing of bone replacement depended upon the size of the defect and the status of the wound. It was sometimes done the day after the first operation. The bone was "shingled" or "bricked" into place until the defect was filled. The wound was closed except for a small opening or vent directly over the graft, which was maintained by a petrolatum-impregnated gauze wick.

Immobilization was found to be most important. The experience in two of the early operations, in which plaster was omitted, indicated that at

least part of the reason for both failures was pocketing of exudate, which prevented granulations from growing up by engulfing the grafts and incorporating them solidly into the recipient site by organization.

In three cases at DeWitt General Hospital, the wound was completely closed over the graft at the replacement operation. More often, small defects were closed when the first cast was changed, usually at the end of 3 weeks. In one instance, a previously prepared abdominal pedicle was swung into place at this time; prompt and complete healing followed. In larger defects, closure was usually accomplished at the end of another 3 weeks if three criteria were met: (1) that no sinus tracts were present; (2) that healthy granulations covered all grafts and recipient bone; and (3) that local soft tissues were not edematous or inflamed.

OTHER METHODS OF MANAGEMENT

Early Wound Closure

The technique of saucerization and dermatome grafts, while it became extremely popular, was not, of course, universally accepted. At Vaughan General Hospital, Lt. Col. Thomas Horwitz, MC, and Capt. Richard G. Lambert, MC, took the position that the "drive" to eliminate infection in osteomyelitis by surgical means appeared to exaggerate, sometimes greatly, already existing soft-tissue and osseous problems of reconstruction (*21*). They advocated, instead, excision of sinus tracts and necrotic skin margins, with removal, at the same time, of obviously dead and denuded bone. Anything that seemed at all viable was spared. For this reason, sharp bony edges and bony prominences and irregularities were not removed unless they seemed likely to interfere with wound healing.

The skin was undermined freely, sometimes to half of the circumference of the wound. This measure often permitted closure of the skin, or at least a reduction in the size of the wound gap. The upper and lower portions of the incision were closed with mattress sutures of silkworm gut or wire, with buttons applied to prevent the sutures from cutting into the skin. The central portion of the wound was left open. Drainage was instituted, and the extremity was put up in plaster or in balanced suspension skeletal traction.

On the fifth day, the drain was removed and the sutures that had been preplaced in the center of the wound were tied if appearances warranted these procedures. The sutures were removed on the 10th postoperative day and immobilization was maintained for another month. The subsequent management depended upon the appearance of the wound and the progress of bony union.

In the first cases in which this technique was used at Vaughan General Hospital, all apparently infected bone was radically resected. The resulting

bony gaps, prolonged drainage, shortening, and deformity introduced serious problems of reconstruction. Convalescence was dragged out and functional restoration was delayed. Thereafter, extreme conservatism was practiced in the excision of bone, particularly in such areas as the lower end of the femur, the upper end of the tibia, and the os calcis. In a number of such cases, given enough time, the defects filled in spontaneously with scar tissue, and the residual column of bone was sufficiently sturdy to assume functional responsibility.

In the 125 operations that made up this series, it was thought that only two patients, both with defects of the upper tibia, would require plastic reconstruction of any magnitude. Extensive undermining of the skin, to permit complete or partial closure after conservative bone resection, did not cause a spread of infection in any instance. On the contrary, in the opinion of Colonel Horwitz and Captain Lambert, this technique offered a rapid method of closure with adequate skin; lessened the need for plastic surgery; reduced scarring; provided a more satisfactory bed for whatever reconstructive surgery might be necessary; and, in general, resulted in control of osteomyelitis with the least possible sacrifice of soft tissue and bone.

When complete skin closure by the technique just described was not immediately possible or advisable, healing of the skin defect was materially hastened by early application, to receptive surfaces, of either split thickness or large pinch skin grafts. They served as temporary dressings, in preparation of the field for definitive reconstructive measures, and were particularly useful over bony prominences or easily traumatized areas.

Muscle Transplantation

At DeWitt General Hospital (*6*), the preferred method of handling rigid-walled bone defects was by transplantation of viable muscle, as advocated by Starr in 1922 (*25*) and Mercer (*26*) in 1943, followed by wound closure. Areas in which this method could safely be used (that is, in which there was sufficient muscle tissue about the bone focus) included the scapula, the clavicle, the humerus, the radius (except the radial styloid) and ulna, the metacarpals, the pelvis, the femur, the fibula, the metatarsals, the vertebral processes, and the ribs. If tibial defects were handled by this method, careful selection of cases was necessary.

The operation was performed with a pressure cuff tourniquet in situ. Methylene blue was injected into all sinus tracts under slight pressure, to aid en bloc excision; this was a useful measure, for such tracts were often multiple and tortuous. The incision was extended well into normal areas proximal and distal to the evident pathologic process. Wide exposure was necessary for adequate visualization of diseased tissue and for isolation of peripheral nerves and important vessels in the area. It was also necessary

for proper selection of the portion of muscle that would be formed into the pedicle. This step of the operation was so carried out that innervation and vascularization of the donor muscle and the blood supply of the pedicle would not be jeopardized; that there would be minimal interference with the function of the part; and, in short, that a viable pedicle would be secured.

All scar tissue, sinus tracts, infected granulation tissue, sequestra, eburnated and abnormal bone, and accessible foreign bodies were removed radically until all remaining tissue appeared normal and well vascularized. If the bone defect was shallow, it could then be obliterated by slight displacement of the surrounding muscles. If the defect was deep, a muscle pedicle was created and sutured into it. The wound edges were loosely approximated, and drainage was instituted for 48 hours.

Some wounds were closed by delayed primary wound closure in 5 to 7 days. Relaxing incisions frequently permitted closure of the skin and superficial fascia.

SPECIAL STUDIES

The official figures for osteomyelitis in World War II (6,465 admissions) have been discussed elsewhere (p. 283). The numbers of small series studied in various hospitals, frequently to establish the value of one method of treatment over another, are of more usefulness from the clinical standpoint, and several of them are cited for that reason.

Vaughan General Hospital.—At Vaughan General Hospital, 75 patients with chronic osteomyelitis complicating battle-incurred compound fractures were treated by ostectomy and delayed wound closure between 15 September 1944 and 1 March 1945 and were evaluated up to 15 September 1945 (*21*). At this time, 73 wounds were completely healed, 41 within 2 months of operation. In another 31 cases, healing occurred after periods of drainage lasting up to 9 months. In still another case, osteomyelitis of the os calcis, several well-localized sequestra were removed and the walls of the cavity collapsed after drainage had persisted for 10 months; healing was then complete within 10 days.

In one of the two failures in these 75 cases, an instance of localized osteomyelitis of the femoral neck, reoperation was necessary 7½ months after the primary operation. In the second failure, an extensive infection at the upper end of the tibia with involvement of the knee joint, drainage had persisted for 8 months and a second ostectomy had been planned when the study was concluded.

In this hospital, as in others, osteomyelitis of the long bones which involved adjacent joints proved extremely recalcitrant to treatment. Healing periods of 8 to 9 months were not uncommon.

The 75 cases of osteomyelitis just described were all treated by sys-

temic and local penicillin. Another series of 50 cases were similarly treated except that penicillin was not employed locally; 10 patients were operated on between 15 September and 15 October 1944 and the other 40 between 14 April and 6 July 1945. When these 50 patients were evaluated on 15 September 1945, 46 wounds were found completely healed, 45 within 2 months after operation. It was, therefore, concluded that the local use of penicillin offered no advantages, and this form of administration was discontinued, with decided simplification of nursing care.

Ashford General Hospital.—The unsatisfactory results of iliac bone implants in saucerized wounds at this hospital, where saucerization was developed, have already been mentioned. In 126 cases treated by saucerization, 97 dermatome grafts were replaced by the following techniques and with the following results:

One failure in 13 cases treated by direct abdominal pedicles. When cavitation furnished no problems, this was the most dependable of all procedures. The margin of safety was greater, and closure of the resulting wounds was possible after the transfer of relatively large pedicles.

Four failures in 11 cross-leg pedicles.

Eight failures in 13 local pedicles, including one case in which iliac bone implants were also used.

Two failures in three followed-up patients treated by local excision (excision, muscle transplant, closure).

Four failures in 10 tubed pedicles. In another 37 cases treated by this method, followup was incomplete in 27, and 10 were still in the planning stage.

Nine failures in 10 patients treated by excision of the graft and iliac chip implants. Oddly, this same technique gave good results in four other cases not included in the series.

Billings General Hospital.—Two series of cases, slightly overlapping, were studied at Billings General Hospital.

The first analysis, by Colonel Rice, consisted of 150 patients with osteomyelitis secondary to gunshot wounds treated by saucerization and skin grafting (*2*). All had roentgenologic evidence of infection, and 144 had a history of wound suppuration for 3 months or more; in one instance, the history covered 3½ years. All major bones were involved, and the site of disease was not the determining factor in the selection of this method of treatment. The only cases considered unsuitable for it were those in which skin grafting was mechanically impossible from the anatomic standpoint—perhaps 15 percent of all patients observed with osteomyelitis.

Of these 150 patients, 66 presented dry, clean, healed wounds, covered with healthy skin, on the 25th day after saucerization and dermatome skin grafts. Another 69 wounds were completely healed on the 50th day. In practically every instance, temperature and pulse were within normal range on the third or fourth postoperative day. The remaining 15 operations were rated as failures, either because drainage was persistent or because further surgery was required.

Many of the 135 patients with healed wounds were followed for several

additional months, and in no instance was there the slightest tendency for the wound to break down and suppurate. The only refracture in the series, through the site of the original disease in the femur, was the result of a fall.

A number of hopeful developments were observed after the use of this technique. Bone healing, delayed and faulty for many months, often improved dramatically. Five patients with well-established nonunion promptly progressed to union. In practically every instance in the series, roentgenograms revealed improvement in local nutrition and in the quality of bone texture. Soft tissue responded equally well. Resection of scar tissue and elimination of suppuration improved the local blood supply, and soft tissues filled in so rapidly under the skin graft that the size of the original defect was considerably reduced.

Even more gratifying than the local results was the constitutional improvement in these patients. Rapid conversion of their "dirty, smelly" debilitating wounds into clean, well-healed areas produced a remarkable physical and mental change, which was reflected objectively in their weight gain, appetite, and blood values. It was necessary only to walk through the "old" and "new" osteomyelitis wards to appreciate the difference.

In a number of cases in this series, the skin dressing was removed surgically several weeks, or several months, after healing, for the application of a full-thickness skin graft or other definitive local plastic surgery. In most cases, additional time and observation were needed to determine the capacity of the grafted area to withstand normal wear and tear. In sites in which friction and motion were not significant, the orthopedic surgeons were "conservatively optimistic" about the permanence of skin grafting without further surgery.

The single case of acute hematogenous osteomyelitis observed during the period covered by this surgery showed the same remarkable clinical course described for patients whose disease originated in combat-incurred wounds.

The second study of osteomyelitis at Billings General Hospital, made by Lt. Col. Edward T. Evans, MC, covered the 8-month period ending on 1 October 1945 (*4*). Of the 475 patients observed, 279 were submitted to saucerization and dermatome skin grafting.

Reoperation was necessary in 57 of these 279 patients, 20 percent. The increased efficiency with which the technique was used is evident in the fact that a second operation was necessary in only nine of the last 86 patients treated, 9.6 percent. It is true that many of the patients in this group represented second saucerizations, in which a higher percentage of success could have been anticipated. On the other hand, as pointed out elsewhere (p. 295), many of these patients were treated during the period when avascular necrosis and synovial leakage were considered proof of failure.

In the remaining 196 cases:

Seventy-nine were treated by sequestrectomy and final closure, with eight second operations necessary before healing was finally effected.

One hundred seventeen were treated by saucerization, with 23 second operations. The Orr treatment was used in these cases because they were mechanically unsuited for the combined saucerization-dermatome graft technique.

DeWitt General Hospital.—The series of cases of osteomyelitis analyzed at DeWitt General Hospital consisted of 66 separate foci of bone infection in 64 patients (*6*). The disease was hematogenous in four cases, secondary to surgical infection in six, and secondary to infected compound fractures sustained from falls, vehicular accidents, and gunshot wounds in the remainder.

Followup was long enough (an average of 7½ months) in 42 patients with 44 foci to permit a statement of results. Complete healing was evident in 21 wounds at the first inspection, usually 10 to 15 days after operation, and in 19 others at the end of 5 weeks. In three cases, serous exudation persisted in decreasing amounts for 8 weeks, but there was no recurrence over a 5- to 6-month period of observation.

The single failure in these 44 operations was explained by incomplete removal of eburnated bone, which underwent sequestration. The findings at the second operation, which was followed by a good result, provided all the evidence the staff needed to teach them that excision in osteomyelitis should be radical.

In the 20 cases of chronic osteomyelitis treated at this hospital by radical excision and iliac bone grafts, results were classified as good in eight cases, fair in eight, and failure (persistence of drainage after 4 months) in four.

In one of the cases classified as fair, a sequestrum was inadvertently overlooked at the first operation; healing was prompt after sequestrectomy. Four of the other patients whose results were classified as fair required curettage for elimination of persistent sinuses with serous drainage. Postoperative observation over an average period of 5 months revealed wound healing in all.

Several lessons were learned from these five cases: that the entire area of osteomyelitis must be thoroughly explored at the primary operation, with no overhanging ledges left; that cuplike rather than saucerlike defects are the desiderata when deep foci of osteomyelitis are excised; and that surgical exploration is indicated if any sinus persists longer than 2 weeks after removal of the cast. Better results would have been obtained in all five cases if these precepts had been followed.

The four complete failures in these 20 cases occurred in large defects, two in the upper tibia and two in the skin and subcutaneous tissues near the ankle. In both of the latter cases, bone takes were good but each wound, while without sinuses, remained as a shallow, granulating area, with a scanty serous exudate. Pedicle grafts from the opposite calf area were in preparation when this report was made, and it had been decided that in future cases of this kind, a pedicle graft would be ready to swing within 3

to 6 weeks after the iliac bone graft. This technique had already been used in one case in this series.

The other two failures were believed due to the large diameter of the defect, 4.0 to 4.5 centimeters. It was determined that, in the future, the bone would be so shaped that it did not take the form of the complete well present in these two cases, on the theory that revascularization of the grafts would be rapid enough to win over necrosis only if the diameter of the bed did not exceed 2.5 to 3.0 centimeters.

In retrospect, it was concluded that, under the circumstances, all four of these operations were foredoomed to failure by the methods employed.

Tibial defects presented special problems. They were usually deep, and after excisional surgery, they tended to present rigid-walled cavities which, by ordinary methods, would take months to fill in. In seven such cases, the area of destruction was chiefly cortical or along the lateral or posterior surface. After excision, the superficial defect was obliterated by closure of the skin and subcutaneous tissues or muscle, depending upon the location of the focus of infection. Prompt healing occurred in all. In two other cases in which the tibial shaft was the site of defects, excision and bone grafting were accomplished at the same operation. Healing occurred in both, though it took 2 to 3 weeks longer than usual.

The four instances of suppurative arthritis and osteomyelitis observed at DeWitt General Hospital involved the knee in two cases and the hip joint and the elbow in one case each.

Fifth Service Command.—The largest series of cases of osteomyelitis analyzed in World War II was collected by Lieutenant Colonel Preston, Consultant in Orthopedic Surgery, Fifth Service Command (*20*). It consisted of 1,452 patients, chiefly treated at Ashford, Crile, Fletcher (Cambridge, Ohio), and Billings General Hospitals (and thus it overlaps smaller series collected from some of these hospitals). After saucerization, 260 patients were treated by delayed primary wound closure and 87 by subsequent excision of the graft, followed by obliteration of the defect by iliac bone chips and closure of the soft parts.

The interval between saucerization and delayed primary wound closure was usually 1 to 2 weeks. One month after closure, 190 of the 260 wounds in this series, 73 percent, were healed. At the end of 2 months, 210, 81 percent, were healed. The remaining 49 closures were listed as failures. Obviously, the chances of healing in delayed primary wound closure are rather remote after a month. The chief technical difficulty in these cases, and the most important cause of failure, was the presence of hematomas and dead spaces after closure. A few cases were salvaged by repeated aspiration of hematomas, but the more usual reliance was upon careful hemostasis at operation and the application of pressure dressings to eliminate dead space.

In the 87 cases treated by iliac chip grafts after saucerization and dermatome grafts, the interval between the operations varied from 1 to 4 months. Healing was complete after 1 month in 64 cases, 74 percent, and

after 2 months in 73 cases, 84 percent. The remaining cases were classified as failures.

This technique was used most often in cases in which there was continuity of the bone, but its strength was inadequate for normal use. In a few cases in which there was no continuity at all, a massive bone graft was used in addition to the iliac chips. The same technique was used in cases in which there was inadequate soft tissue for delayed primary wound closure. Most orthopedic surgeons considered it safer to fill the cavity with bone chips than to shift a soft tissue flap over it and leave a dead space.

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CHAPTER IX

Other (Nonorthopedic) Complications

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

The thoracic and other nonorthopedic complications, postoperative and otherwise, of orthopedic injuries were essentially the same as those common to other conditions and operations and to anesthesia. They are discussed at length under the appropriate headings, in other volumes in this historical series and are not repeated here (*1–7*). One special case, however, might be mentioned, as illustrative of the problems inherent in a worldwide war: The only complication in a series of 16 bone-grafting operations at Vaughan General Hospital, Hines, Ill., was a malarial relapse, 3 days after operation, in a patient from the Pacific.

Certain other complications related to orthopedic injuries should be briefly discussed.

ASSOCIATED WOUNDS

No complete collected statistics exist at this time for fractures associated with other injuries, but the association was frequent and its implications were always serious. This is evident in the 3,154 patients with abdominal injuries sustained in combat and treated by the 2d Auxiliary Surgical Group in the Mediterranean theater. They are analyzed in the second volume on general surgery in this historical series (*2*):

Of these 3,154 patients, 1,089 had 1,551 associated wounds. Data suitable for analysis were available in only 1,403 of these injuries.

In these 1,403 injuries were 659 fractures, 47.0 percent, including 238 fractures of the pelvis, 57 of the femur, 23 of the femur and one other major bone, 31 of the humerus, and 21 of the humerus and one other major bone. Analysis of this material left no doubt of the importance of these associated fractures in the case fatality rates. Indriven bone fragments, acting as secondary missiles, were responsible for some of these associated injuries.

When casualties with associated injuries were received in Zone of Interior hospitals, fracture management often had to be modified, or even postponed, until the associated injuries were handled; they often presented more serious problems than the orthopedic injuries.

The following case history illustrates some of the problems inherent in the joint management of fractures and associated wounds (*8*):

Case 1.—This patient sustained a penetrating wound of the ala of the left ilium and a penetrating wound of the abdomen, with retention of the missile in the pelvic tissues.

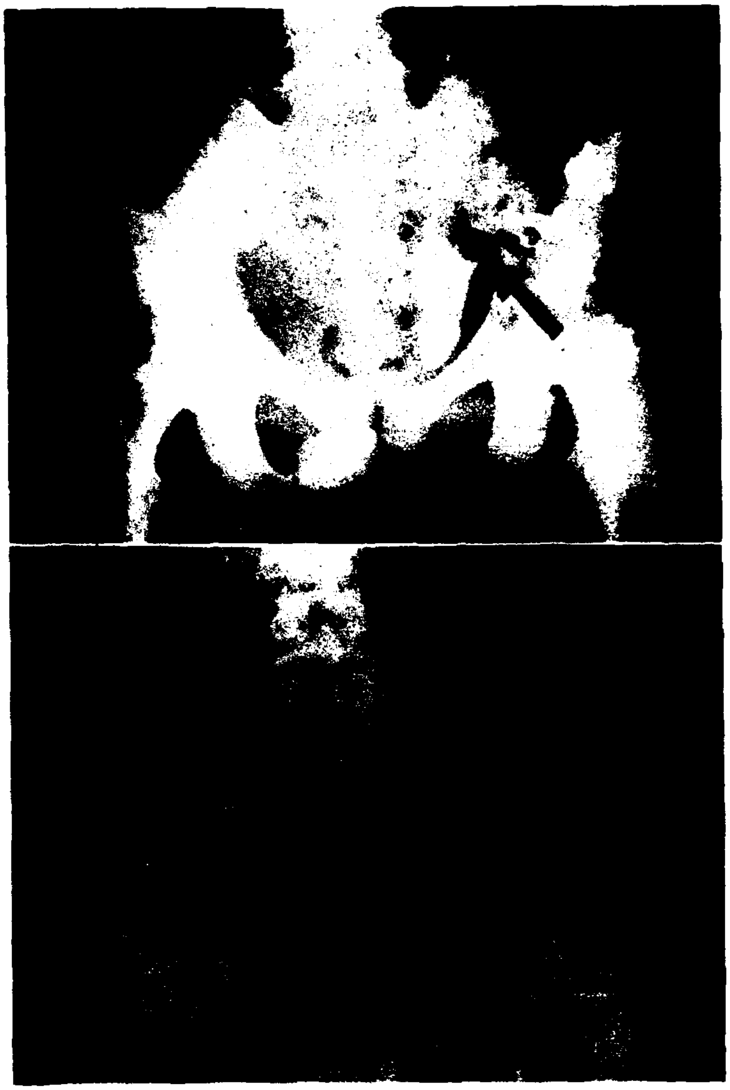

FIGURE 89.—Penetrating wound of abdomen complicating combat wound of left ilium. (Top) Anteroposterior roentgenogram of pelvis, after Lipiodol injection of iliac sinus, showing area of osteomyelitis and sequestration in iliac ala and communication of sinus with large pelvic abscess. (Bottom) Same, after completion of surgery, showing healed osteomyelitis with bony regeneration of ilium. Abscess cavity and fistulae are now healed. Lipiodol in extraperitoneal pelvic tissues is retained from initial injection. (Sanders, G. B., and Hodge, I. G.: Ann. Surg. 125: 399–417, April 1947.)

He underwent debridement, evacuation of a large extraperitoneal hematoma of the left iliac fossa, and proximal sigmoid colostomy at a hospital in the Pacific. When he was admitted to Vaughan General Hospital (fig. 89), he had a partial left sciatic palsy, a large draining sinus of the left iliac region, and chronic osteomyelitis of the left ilium. A large (3- by 4-centimeter sequestrum involving part of the iliac ala also involved

the margin of the greater sciatic notch and lay against the left sciatic nerve and iliac vessels. It was removed, together with a handful of pulped necrotic bone, and the pelvic abscess was drained. There was almost immediate improvement in the sciatic palsy, the osteomyelitis healed promptly, bony regeneration was rapid, and the sinus closed.

SECONDARY HEMORRHAGE

Secondary hemorrhage was a real potentiality in many returned casualties, but actually was exceedingly infrequent. The precautions taken to prevent it, illustrated in the following case histories from Halloran General Hospital, Staten Island, N.Y., explain its low incidence:

Case 2.—When this patient was received, it was noted that he had had a hemorrhage overseas, and the bloody appearance of his cast suggested that he might have another, and soon. Necessary laboratory examinations, including blood typing, were ordered, blood was made available, and a tourniquet was placed around his leg, ready for immediate tightening. He began to bleed before he reached the operating room, but the operation was already scheduled, all necessary personnel had been alerted, and the bleeding from the gunshot wound of the popliteal artery associated with the fracture was under control in a very short time. Loss of blood was minimal, the leg was saved, and the patient was in good condition when he was evacuated 6 weeks later.

Case 3.—This patient had about the same history, and was in about the same conditon, as the patient just described when he was received at Halloran General Hospital, in a night convoy. He was scheduled for operation the following morning. The operating surgeon slept in a room across the hall and his assistants slept in the room with the patient, each of them watching him an hour at a time. He was on the operating table by 0600, and the near erosion of the deep femoral artery was controlled, with salvage of the leg. This patient needed a great deal of blood, but he lost none at Halloran General Hospital.

TETANUS

The story of tetanus in World War II is told in detail in volume III of the Preventive Medicine subseries in this historical series (*9*). It was not a problem. The efforts of The Surgeon General to institute immunization against it in the U.S. Army began in May 1940, and it is frightening to recollect that it was not until 11 June 1941, just 6 months before the United States entered the war, that the recommendation was accepted and the policy implemented.

The policy paid rich dividends. There were only 12 cases of tetanus in U.S. troops, with five fatalities, during the entire war (*10*). The breakdown is instructive:

Six patients, two of whom died, had had no active immunization; in four of the six cases, the causative injuries occurred before the men entered the service.

Two patients, one of whom died, had had their basic immunization (three injections) but did not receive the prescribed booster dose after injury.

The other four patients, two of whom died, had had both basic immunizing injections and booster injections after injury. They represented the only real failures of immunization.

Eight of these 12 cases occurred in the Zone of Interior and the other four occurred, respectively, in the Mediterranean, European, and China-Burma-India theaters and in the Southwest Pacific Area.

CLOSTRIDIAL MYOSITIS (GAS GANGRENE)

Clostridial myositis (gas gangrene) was a problem chiefly of overseas theaters, and it is startling to read, in the May 1944 issue of *The Bulletin of the U.S. Army Medical Department* that its "general incidence * * * thus far closely approximates that of the last war" (*11*). Since treatment was highly unsatisfactory, prophylaxis was of the utmost importance. It was easy to attain. It consisted simply of the removal after trauma of all tissue in which the circulation was lost or dangerously impaired; avoidance of procedures and appliances that might jeopardize the vascularization of the affected part, such as the use of unpadded and unsplit casts, circular bandages and tourniquets, and tight plugging of wounds; provision for adequate drainage; and nonclosure of all wounds.

These precautions were easy to follow in Zone of Interior hospitals and were generally observed. The occasional exception, however, could have disastrous consequences. The reason for the issuance of Circular Letter No. 189, Surgeon General's Office, 17 November 1943 (*12*), was that, on a recent inspection trip by the Consultant in Orthopedic Surgery, three patients were observed who had required guillotine (circular) amputation for gas gangrene because regulations had not been followed (p. 892). In two cases, the wounds had been closed, and in the other, debridement was incomplete. It was "strictly forbidden," the letter specified, that any compound fracture or any extensive wound of the extremities be closed after debridement; debridement should be performed as soon as the patient's condition permitted; and only light packing should be used in the wound.

At the Army Air Forces conferences in October 1943 (*13*), the importance of leaving wounds open was emphasized, and it was pointed out that even closure within the optimum (golden) period was no longer permissible. The basis of the prohibition was that there was always some element of chance in closing a compound fracture immediately after trauma and debridement, and in military surgery that chance was not permissible. Two cases of gas gangrene which required amputation were described, both of which had originated in closed wounds.

When clostridial myositis did occur, conservatism was justified until the trend of events became clear. Treatment was directed toward controlling the infection and combating the toxemia by the use of antitoxin, sulfonamides, penicillin, supportive measures, and resectional surgery. Amputation was a last resort.

Once the infection was controlled, there were no known instances in the Zone of Interior in which, as sometimes happened in the First World War, the original infection flared up when corrective or other surgery was carried out.

FAT EMBOLISM

The definitive World War II article on fat embolism was prepared by Comdr. Shields Warren, MC, USNR, from material available at the Army Institute of Pathology, Washington, D.C. (*14*). As he pointed out, this condition was a "pathologic curiosity" in time of peace but a problem of real clinical importance in time of war because of the inevitable increase in trauma in wartime. His further statement, that there was no effective therapy for it, was unfortunately also correct.

Basic Data

Commander Warren's material consisted of 100 consecutive cases from the Institute files, beginning with the large scale mobilization in 1941 and ending in late 1944. The patients, with one exception, were all young, healthy men. Their ages, in the 81 cases in which age was stated, ranged from 18 to 38 years, with 59 patients in the 18- to 25-year group.

Incidence

The reported incidence of fat embolism varies widely:

Darrach, in 1939, reported two cases in 12,000 fractures at the Presbyterian Hospital in New York (*15*).

Robb-Smith, in 1941, studied 789 consecutive bombing incidents, of which 125 were fatal (*16*). In 41 of the fatalities, gross pulmonary fat emboli were present; and in 29 of these, pulmonary embolism was a major factor in the fatality. In six of the 12 fatalities in which there was no bony injury, death was also caused by fat embolism.

Wilson and Salisbury, in 1944, reported eight cases of fat embolism, six of them fatal, in 1,000 British casualties at a hospital in Malta (*17*).

Official figures for World War II show only 20 cases of fat embolism. In a long experience in the Zone of Interior and later as Senior Consultant in Orthopedic Surgery in the European theater, Col. Mather Cleveland, MC, saw only one case. It developed in a soldier with a closed fracture of the femur, treated at the station hospital at Fort Jackson, S.C., by open reduction and internal fixation. The diagnosis was confirmed by neurologic consultation. Three years after the war, this man was examined by Colonel Cleveland and his recovery was reported to Dr. Eldridge H. Campbell, Jr., (formerly Colonel, MC), the consultant in the case.

Etiology

Motor vehicles were responsible for 61 of the injuries, in the Warren series, and a horse, a mule, a street car, a parachute, and a glider were each responsible for one injury. The embolism followed fractures of one or more

bones in 91 cases. In the other nine cases, it followed blast injuries without fractures (four cases), burns (three cases), pressure asphyxia without fracture (one case) and trauma from shell fragments (one case). The localization of the 91 fractures was notable; the tibia, the femur, or both of these bones were involved in 75 cases, about 82 percent.

So far as is known, the total amount of body fat plays no part in the occurrence of fat embolism. In 23 of the 85 cases in this series in which the body weight was stated, the patients were overweight. Extremely obese or extremely emaciated men would naturally not be included in such a series, as they would not have been accepted for service.

The body weight and the blood pressure were not considered factors in the pathologic process, but the state of the circulation was of some importance. A man with impaired circulation naturally felt the effects of the embolism more than one with good circulation. Commander Warren, however, was unwilling to accept status lymphaticus as a predisposing factor in any properly studied fatality.

Pathogenesis and Pathologic Process

Concussions and burns were somewhat difficult to explain as the background for fat embolism, but in the 91 fractures in this series, the three factors considered essential for the entry of embolic fat into the circulation were all operative. They are (1) mobilized fat, set free from marrow cells; (2) disrupted and patent veins and venules, without opportunity for collapse of their walls; and (3) local pressure, which becomes greater than venous pressure as hemorrhage, edema, and exudation develop about the fractures. Under these circumstances, it is easy for fat to find its way into the disrupted and patent venous channels. A considerable degree of local pressure exists after local swelling has occurred, and any mobilization of the fracture at this time is hazardous: The manipulation may dislodge the fibrin that occludes the disrupted veins and thus open them to the entrance of any free fat present.

The amount of fat present in the veins does not seem as important as its physical state. As long as it remains finely divided, it is not dangerous, and no convincing evidence was adduced in this study that chylomicrons coalesce to form masses able to cause embolism. Moreover, the level of total fat in the blood may not be high. Determinations were run in only a few of the cases that Commander Warren studied, but they were not abnormal in any instance.

Recorded estimates of the minimal lethal amount of fat entering the human circulation range from 12 grams (*18*) to 120 cubic centimeters (*19*). Animal evidence is conflicting and, for other reasons, cannot be applied to clinical data. The cases in this series demonstrated that, when circumstances were appropriate, fracture of a single bone might release enough fluid fat into the circulation, at a sufficiently rapid rate, to cause death.

Clinical Considerations

In many of the cases studied, a period without symptoms ensued after trauma, its end often being foreshadowed by a feeling of marked apprehen-

sion, the same sort of feeling often present in pulmonary embolism of other origins. Fever was inconstant and might be related to other findings. Physical examination and roentgenograms were of little help, but the presence of pulmonary edema in a patient who had recently sustained trauma often led to the suspicion of fat embolism. Lipuria was only occasionally observed, and examination of the blood for fat seemed of little value. At the end of 36 hours, fat globules were sometimes present in the sputum. Autopsy was frequently necessary to determine the cause of death. The average time from symptoms to death was 53 hours and the longest interval, 25 days.

The cases studied at the Army Institute of Pathology were classified, according to the categories described by Bürger in 1915, as:

Peracute, with death in a few seconds (nine cases).

Acute, with symptoms appearing immediately after injury and death occurring in from hours to days (17 cases). Cases in this group were often diagnosed as pulmonary edema.

Subacute, with a free period between trauma and the onset of symptoms (58 cases).

The remaining 16 cases could not be classified.

In 34 cases, respiratory symptoms were the most striking clinical feature at death. In 24, the symptoms were predominantly cerebral. Brain involvement followed the classical pattern. A rapid rise of temperature, in the absence of pneumonia, suggested cerebral involvement in the embolic process in some cases. Renal damage seemed to play no part in any of the fatalities.

Post Mortem and Histopathologic Observations

When death occurred rapidly, the only gross findings at post mortem might be an excess of oil droplets in the pulmonary circulation. In acute cases, there was usually pulmonary edema, with petechial hemorrhages, usually perivascular, in the brain. In cases of longer duration, there was sometimes consolidation of the lungs, in addition to edema and hemorrhage, with evidences of asphyxia in the form of marked congestion of the chest, neck, and head, as well as petechial hemorrhages. Microscopic examination (figs. 90 and 91) revealed fat droplets in the small vessels and capillaries of most tissues, predominantly in the lungs and in the glomerular tufts of the kidneys. In four cases, the pulmonary fat was classified as 1+, in 34 as 2+, and in 62 as 3+.

In three of the 100 cases in the series, fragments of bone marrow were present along with fat in the pulmonary vessels. Although the finding is not at all usual, three similar cases were observed by Capt. Henry D. Moon, MC, in the Laboratory Branch, Letterman General Hospital, San Francisco, Calif., and were studied in association with Dr. Stuart Lindsay, from the Division of Pathology, University of California Medical School (*20*). Their review of the literature indicated that only two such cases had previously been reported, one by Schenken and Coleman in 1943 and the other by Henke and Lubarsch in 1931.

The cases observed at Letterman General Hospital were as follows:

Case 4.—A 21-year-old sailor entered the hospital shortly after falling out of a rapidly moving train. He had multiple injuries, including an extensive laceration ex-

FIGURE 90.—Pulmonary fat embolism. Paraffin section of glomerular tuft showing vacuolization of capillaries and arteriole due to embolic fat. Case 118020. Hematoxylin-eosin stain. (× 500) (Warren, S.: Am. J. Path. 22: 69–87, January 1946.)

tending into the lateral aspect of the right knee joint and an oblique fracture through the lower portion of the lateral condyle of the right femur. The temperature, 103° F. on admission, rose to 105° F. before death. The respiratory rate, 28 per minute on admission, rose to 50, and the pulse rate, 120 per minute on admission, rose to 156. Over a 7-hour period, the patient had 10 generalized convulsions. Death occurred 39 hours after injury and 34 hours after the onset of convulsions.

At autopsy, the lungs were found to be large, voluminous, tense, and firm. Both pleural and cut surfaces showed a distinct mosaic appearance with alternating zones of marked congestion, hemorrhage, and grayish consolidation. A large amount of frothy, sanguinous fluid exuded from the cut surfaces. There were also hemorrhagic changes in the brain. Histologic changes were limited to the lungs and brain. The pulmonary arteries and veins and the capillaries of the alveolar walls were distended with blood. In one of the many pulmonary sections made was a branch of the pulmonary artery, measuring about 370 by 950 micra, the lumen of which was almost completely filled with a large fragment of well-defined bone marrow, which consisted of numerous fat cells, erythropoietic and myelopoietic cells, several megakaryocytes, and supporting connective tissue cells. This segment of marrow could be followed, by serial sections, in the vascular lumen for about 70 micra. The marrow embolus lodged at the bifurcation of the vessel, and extensions from it could be followed into the two branches. These branches measured 250 and 340 micra in diameter, respectively, and were almost completely filled with the embolic mass.

Case 5.—A 45-year-old merchant seaman, while drunk, was strangled and thrown down a steep rocky cliff. He was found dead some hours later. Autopsy revealed multiple injuries, including multiple fractures of the skull, sternum, left clavicle, mandible, right radius, ribs, and seventh thoracic vertebral body. In addition to subpleural asphyxial hemorrhages, both lungs were found mildly congested and edematous. In one of the numerous sections of lungs, the lumen of a branch of the pulmonary artery, measuring about 240 by 640 micra, was almost completely occluded by a fragment of bone marrow. The embolus was composed of well-defined erythropoietic and myelopoietic elements and a few fat cells, but there were no megakaryocytes, and the marrow embolus could not be demonstrated in serial sections.

FIGURE 91.—Pulmonary fat embolism. Paraffin section of glomerular tuft showing vacuolization of capillaries and arteriole due to embolic fat. Case 117306. Sudan IV stain. (× 500) (Warren, S.: Am. J. Path. 22: 69–87, January 1946.)

Case 6.—A 23-year-old soldier, on a motorcycle, collided with an automobile and was dead on arrival at the hospital a few minutes later.

In addition to multiple other injuries, autopsy revealed multiple comminuted fractures of the skull and sternum and fractures of the left radius and ulna, left femur, and right tibia and fibula.

In one of several sections of pulmonary tissue was a single branch of a pulmonary artery measuring about 215 by 400 micra and containing a fragment of well-defined bone marrow. This material, which almost filled the lumen, was composed of erythropoietic and myelopoietic elements, two megakaryocytes, and several fat cells. The embolus could not be demonstrated in serial sections. Sudan IV stains were not done on the cerebral, renal, and pulmonary tissues, but there was no vacuolization of the vascular contents in them to suggest the presence of lipid globules. This stain demonstrated only a few globules in the vessels in case 5 but many in the larger pulmonary vessels and capillaries of the alveolar walls in case 4.

An interesting feature of these three cases is the swiftness with which post mortem was done. The authors are probably correct in their statement that bone marrow embolism after fractures is "a common process" but that to demonstrate "the few fragments of marrow liberated into the vascular system at the fracture site," it would be necessary to examine the entire lung by sections. Since such a routine procedure would be impractical, one must agree with their conclusion that "The finding of such emboli in a few random sections of pulmonary tissue is purely accidental."

Therapy

The pathologic process in fat embolism is such that there is no specific therapy for it. The supportive treatment applied is usually futile except,

possibly, for the administration of oxygen, to prevent further development of anoxia and pulmonary edema. As for prophylaxis, the important consideration is that fractures be immobilized to the greatest possible degree and that any manipulations be carried out either before appreciable local swelling has occurred or after it has subsided.

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Part IV

FRACTURE MANAGEMENT

CHAPTER X

General Considerations of Fracture Management

George K. Carpenter, M.D., Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

HISTORICAL NOTE

The British and United States official medical histories of World War I contain a great deal of priceless information, much of which is concerned with the management of orthopedic injuries (*1–10*). It is true that U.S. Army medical personnel participated independently in World War I for only a short time, but the total orthopedic experience, supplemented by the far longer orthopedic experience of the British, resulted in the evolution of a technique of management of injuries of the bones and joints that could have proved extremely valuable if it had been employed immediately in World War II.

It was not. Many months, as already pointed out (p. 255), were to elapse before the World War I technique was again evolved, again by trial and error, at the cost of considerable morbidity and, undoubtedly, some lives. Almost no use had been made of the World War I technique in civilian practice between the wars, and it was not utilized in the training of medical officers, either when it became evident that U.S. participation in World War II was inevitable, or later, after this country actively entered the war. Moreover, this technique was not included in any of the early directives issued in World War II. Finally, practically none of this information was incorporated in the military manual entitled "Orthopedic Subjects," which was published in 1942, under the auspices of the Division of Medical Sciences of the National Research Council, with forewords by the Surgeons General of the Army and the Navy (*11*) (p. 36).

Wound closure had been practiced in the early days of World War I, but healing was not satisfactory, and the technique was abandoned (*8*). When the method was revived in 1917, there was careful selection of cases and two criteria were insisted on; namely, aseptic conditions and complete removal of damaged tissues and foreign bodies. The earlier debridement was carried out, and the more inclusive it was, the better were the results. Free incisions were necessary to provide access to the deeper parts of the injury, but unnecessary excision of skin militated against satisfactory wound closure.

Two articles published in 1919 are important contributions to the World War I history. One, by Col. Joseph A. Blake, MC (*12*), described the

management of gunshot fractures of the extremities by wide incision of the overlying wounds; adequate debridement of all devitalized tissue; conservation of bone fragments, to preserve, as far as possible, the continuity of the shaft; and closure by primary suture, delayed primary suture, or secondary suture, according to the circumstances. The other publication, by Eugene H. Pool, M.D., and John H. Jopson, M.D. (*13*), outlined the same technique, emphasizing (1) that delayed primary wound closure could be carried out in most compound fractures of the long bones with little risk and few failures and (2) that the temptation to remove bone fragments freely should be resisted. Immediate closure of the joint capsule in wounds of the knee joint and delayed primary closure of the overlying skin were also advocated.

The recommendations of these observers were based on sizable series of casualties treated by adequate debridement of devitalized muscle and other damaged soft tissue, removal of foreign bodies, and competent management of compound fractures. Even without the aid of antibiotic agents, which then did not exist, satisfactory results were accomplished in more than 80 percent of the injuries in which these measures were employed.

This technique, however, never came into general use in the U.S. Army. For one thing, as already mentioned, the independent U.S. orthopedic experience was relatively brief. For another, the use of this method was limited to a relatively small number of highly competent, widely experienced, top-ranking medical officers, and the information was not relayed to the outlying forward hospitals in which the majority of casualties to whom these methods were applicable were treated. The war, in fact, was over, as the dates of the publications cited indicate, before the information appeared in the U.S. medical literature.

INCIDENCE OF COMBAT- AND NONCOMBAT-INCURRED FRACTURES

In all of the major wars in which the United States has engaged, battle casualties caused by injuries involving the bones and joints have involved from 60 to 70 percent of the wounded who survived to reach forward hospitals. Both in seriousness and in frequency, these injuries have constituted a formidable orthopedic problem.

In World War I (*10*), there were 16,339 casualties with battle-incurred single and associated fractures of the long bones of the extremities, divided as follows: femur, 3,850; fibula, 2,651; humerus, 3,848; radius, 2,267; tibia, 2,486; and ulna, 1,237. There were 2,019 deaths in these 16,339 casualties, the largest number, 971, in the 3,850 fractures of the femur.

In World War I, there were also 39,569 fractures not associated with combat (*10*). Of these, 31,776 fractures were simple, with 664 deaths, and 6,006 were compound, with 663 deaths.

In World War II, official figures show 599,724 admissions for battle injuries with 20,930 deaths, and 16,941,081 admissions for nonbattle injuries, with 76,407 deaths

(*14*). Over the same period there were 148,648 admissions for battle injuries of the bones and joints outside continental United States and 407,211 admissions for non-battle injuries of these structures in the same areas.

As so frequently happens, the total official figures do not represent the clinical situation as well as far smaller, individually studied series of injuries, some of which are cited later. A considerable number of such collected series, unfortunately, could not be used because a fundamental principle was not observed in their preparation; namely, that a clear-cut distinction must be made between (1) simple and compound fractures sustained in the Zone of Interior and typical of civilian injuries and (2) combat-incurred injuries sustained overseas and received in Zone of Interior hospitals 6 weeks or more after injury. The premises were totally different, and it is regrettable that the distinction was not borne in mind in every analysis of procedures and results.

OFFICIAL POLICIES OF FRACTURE MANAGEMENT

January 1942

In Circular Letter No. 1, Surgeon General's Office, 2 January 1942, paragraph 32 of Section IV (Professional) was devoted to fractures (*15*). The date should be noted, for these instructions represented the official policy for the management of these injuries when the United States entered World War II. In substance, the information in this letter was as follows:

1. Recently, in both civilian and military practice, fracture management has assumed increasing importance. For reasons of origin, chiefly the increased hazards of motor transportation, fractures are often multiple, frequently compound, and usually accompanied by extensive soft-tissue involvement.
2. Experience, keen judgment, and proper equipment are essential for good results. Only in general and in large station hospitals are there, as a rule, officers well trained in orthopedic surgery with the necessary special equipment and roentgenologic facilities to treat severe, complicated fractures successfully.
3. Prompt institution of proper management and its maintenance throughout the period of healing are essential to successful fracture management. Poor results produced by improper early management are often irreparable, even though the patient later may come under the most favorable professional care.
4. Unsatisfactory results can be expected when plates and screws of different materials are used in the same injury.
5. In view of these considerations, it is the desire of The Surgeon General to impress upon all medical officers their responsibilities in the management of fractures and the advisability of effecting early transfer to general or large station hospitals of all patients whose extensive injuries or attendant complications contraindicate their care at smaller hospitals.

The stated objectives of this circular letter, which was a compilation of individual circular letters and was not issued until 10 July 1942, was to "consolidate in convenient form all instructions or informative material"

extending back to 1918. Three things impress one about the letter: (1) the lack of urgency in the presentation; (2) the entirely general nature of the directions; and (3) the fact that of the five subparagraphs, the longest and most specific concerned materials for internal fixation, a technique which was to give rise to a great deal of controversy during World War II (p. 377).

March 1942

War Department Technical Manual 8–210, "Guides to Therapy for Medical Officers," issued on 20 March 1942 (*16*), had lost the civilian tone of the earlier circular letter:

1. Death may follow fractures early as a result of shock or hemorrhage, or late as a result of infection, but all of these dangers are increased by transportation without proper traction splints. The dictum, "*Splint where they lie,*" is therefore highly important.
2. Immediately after injury, especially after a fracture caused by gunshot wounds, a period of paralysis of the muscles of the injured extremity occurs, soon followed by a period of spasm. During the spastic period, muscles contract and bony fragments are driven into the soft tissues, with resultant pain and shock, which can be avoided if splinting is carried out promptly, before this period ensues.
3. Relief of pain, treatment of shock, and administration of antibiotics follow standard practices (which are detailed in other volumes of this historical series (*17, 18*)).
4. If the fracture is compound, the clothing is cut away from the wound, hemorrhage is controlled, and a dressing is applied. It is most important that no attempt be made at this time to cleanse or debride the wound.
5. After transportation splinting is applied, the patient is immediately transported to a hospital, with due care taken to maintain body heat.

The detailed directions given in this manual for transportation splinting are essentially those described in other volumes of this series (*19, 20*).

October 1943

When Circular Letter No. 178, Surgeon General's Office, dealing with the care of wounded in theaters of operations, was issued on 23 October 1943, there had been enough experience overseas in the Pacific and in North Africa for policies of management to have become more realistic (*21*). The directions for the management of injuries of the bones and joints set forth in this letter are summarized here because they furnish the basis for the treatment that was continued when the patient reached the Zone of Interior:

1. Open reduction of simple fractures will be done only in general hospitals.
2. Casualties with fractures of the femur will be evacuated from field units to forward hospitals in army half-ring splints. Those with fractures of the shaft of the femur or the tibia or with fractures involving the hip or the knee joint will be similarly

evacuated with skin or skeletal traction or in a plaster spica. The Tobruk splint has received favorable comment.[1]

3. In general hospitals, fractures of the femur will be treated by either skin or skeletal traction until enough union has been obtained to permit safe transportation in a plaster spica.

4. Fractures of the ankle and foot are best evacuated in padded posterior and lateral wire ladder splints.

5. Fractures of the humerus should be transported to evacuation hospitals in the Thomas arm hinged splint with skin traction and triangular bandages, or with the arm immobilized in a sling or Velpeau bandage incorporating a padded external splint if one is available. For evacuation to a general hospital a U-shaped molded plaster splint should be used, supported by bandages and a sling.

6. Fractures of the elbow and forearm should be immobilized in a posterior wire ladder or molded plaster splint extending beyond the wrist and supported by a sling.

7. *Penetrating wounds of the joints* are treated by debridement, removal of loose bone fragments, irrigation, and closure of the synovial membrane but not of the soft tissues. In the upper extremity, all loose bone fragments are removed. In the lower extremity, fragments which can be utilized for stability and weight-bearing are preserved to the degree possible.

8. Fractures of the lumbodorsal spine are transported with a blanket roll supporting the site of the fracture. Fractures of the cervical spine are transported in an improvised collar support.

9. All casts should be padded and completely bivalved before evacuation.

July 1944

Chart 2, reproduced from the *Air Surgeon's Bulletin* for July 1944 and prepared by Lt. Col. (later Col.) Alfred R. Shands, Jr., MC, is a convenient summary of techniques of management for common fractures and dislocations (*22*). These methods had been used up to this time and they continued as official policy throughout the remainder of the war.

PRINCIPLES OF MANAGEMENT IN ZONE OF INTERIOR HOSPITALS

The best fracture management in Zone of Interior hospitals was accomplished by orthopedic surgeons who considered a combat injury more than a break in the continuity of a bone (p. 339). They also regarded such injuries as functional breaks in the continuity of the neuromuscular, vascular, and gliding mechanisms of the extremity. Finally, they remembered that these injuries were often associated initially with shock due not only to the orthopedic injuries but also to visceral, neurosurgical, and other injuries. Many disabilities resulted because surgeons, accepting the limited

[1] The Tobruk splint was a Thomas leg splint, with traction applied to the lower leg or to the boot with adhesive strips. Plaster of paris was applied over the site of the femoral fracture and incorporated in the sidearms of the Thomas splint (*20*). In spite of its popularity with the British Army surgeons, the Tobruk splint had a very limited use in the Mediterranean theater and was seldom used in U.S. casualties in the European theater. It was less effective and less comfortable than a plaster spica in transportation of the wounded with fractures of the femur.—M. C.

CHART 2.—*Suggested therapy for the more common fractures and dislocations*

	SITE	REDUCTION	IMMOBILIZATION	TIME (weeks)	PRECAUTIONS
FRACTURES OF THE HAND AND WRIST	Lower end of radius, including Colles	Immediate; preferably under general anesthesia.	Plaster splints or bivalved cast in position of volar flexion and ulnar deviation except in reversed Colles which should be in extension.	4–6	X-ray all sprained wrists in at least three positions (anteroposterior, lateral and oblique) to rule out a scaphoid fracture. If there is prominence on the volar surface, V-ray it to rule out semilunar dislocations. X-ray a Colles fracture after reduction; never be satisfied until the joint lines are restored to normal. Do not extend the anterior splint for a Colles fracture beyond the proximal crease of the palm; insist on immediate and frequent active motion of the fingers and shoulder after immobilization. Apply skeletal traction immediately for an oblique, overriding, fracture of a metacarpal or phalanx. Do not allow flexion of a finger after a "baseball finger" injury for 6 weeks.
	Scaphoid of wrist	None.	Plaster cast from elbow to knuckles and proximal crease on palm, incorporating thumb to terminal phalanx; thumb in extreme abduction, wrist in about 30 degrees dorsiflexion and 20 degrees of radial deviation.	12, or longer	
	Semilunar dislocation	Immediate; by hyperextension with force against the dislocated bone as the wrist is flexed, or by straight traction on hand.	Anterior splint or plaster cast.	3–4	
	Metacarpals	By traction which may be skeletal.	Roll of bandage or palmar ball splint, preferably with anterior board, plaster, or molded splint.	3–4	
	Phalanges	By traction which may be skeletal.	Anterior plaster, board, or metal splints. "Baseball finger" in hyperextension; proximal phalanx in flexion; middle and terminal phalanges in extension.	3	
FRACTURES OF THE UPPER ARM, ELBOW, AND FOREARM	Shaft of the humerus	Immediate; by traction and manipulation.	"Hanging" plaster cast from axilla to knuckles and proximal crease of palm.	6–8	Volkmann's ischemic contracture of the forearm and hand, the most serious of all fractures, can often be avoided by promptly and immediately relieving all constriction and pressure over blood vessels at the elbow; surgery may be necessary. After reducing a fractured elbow and immobilizing in acute flexion, observe the circulation and sensation in the hand and fingers hourly for the first 24 hours. Record all neurological and circulatory disturbances in fractures and dislocations of the upper extremity. Do not apply a circular plaster cast to an elbow or forearm fracture without bivalving or splitting and spreading the plaster to allow for swelling. For fracture of the humerus, the patient should be kept in an erect or semi-reclining position for 10 days to 2 weeks after reduction and application of a "hanging" cast.
	Supracondylar, condylar, or "T" fracture of the humerus	Immediate; in presence of little to moderate swelling; in presence of marked swelling, gentle manipulation for alinement only.	Posterior plaster splint or bivalved cast from shoulder to knuckles with elbow in flexion.	3–4	
	Olecranon of ulna	Open operation in all fractures with separation of fragments.	Posterior plaster splint or bivalved cast with elbow in full extension.	4–8	
	Head of radius	Not satisfactory; operative removal if displaced or comminuted.	Posterior plaster splint or bivalved cast with elbow at right angle or partly flexed; in undisplaced fractures, use sling only and start early motion.	3	
	Upper third of ulna with anterior dislocation of head of radius	Immediate; open plating of ulna and closed reduction of dislocation.	Posterior plaster splint or bivalved cast with elbow in flexed position.	4	
	Shafts of radius or ulna or both	Immediate; closed manipulation; if unsuccessful, consider plating of fractures or skeletal traction through lower end of radius and ulna with counter skeletal traction through olecranon.	Anterior and posterior plaster splints or bivalved cast from knuckles and proximal crease of palm to axilla.	4–6	
	Posterior dislocation of elbow	Immediate; under general anesthesia.	Posterior plaster splint or bivalved cast followed by active motion.	10 days	
FRACTURES AND DISLOCATIONS OF THE SHOULDER GIRDLE	Clavicle	Immediate; by manipulation and abduction of the shoulders.	T-splint with armsling. Adjust splint daily to maintain abduction of shoulders. Figure-of-8 bandage is sometimes satisfactory.	4–6	Do not allow full motion for 6 weeks after primary anterior dislocation of the shoulder. In fracture of the shaft of the clavicle keep both shoulders well abducted and the affected extremity supported until the union is complete. Maintain complete reduction of an acromioclavicular dislocation by adequate dressings for at least 6 weeks.
	Scapula	None except in marked displacement when traction on the upper arm may be necessary.	Velpeau dressing until pain has subsided, followed by a sling for the arm of the affected side.	3–4	
	Dislocation of shoulder	Immediate; by traction, arm in position, with gentle internal and external rotation; if unsuccessful, Kocher maneuver. Analgesia or general anesthesia.	Shoulder cap of adhesive and sling or Velpeau dressing.	6, primary 3, recurrent	
	Head and neck of humerus	Immediate; by traction and manipulation.	"Hanging" cast with early circumduction exercises.		
FRACTURES OF THE HIP, THIGH, AND KNEE	Hip	Nail fracture after manipulation and reduction, under general anesthesia.	Advisable to apply bivalved plaster cast or traction immediately after reduction and nailing.	16–24	Do not move a thigh or hip injury with possible fracture until the lower extremity has been immobilized in a Thomas splint with traction. In a fractured femur, treat pain with morphine, shock with blood plasma and intravenous fluids. Always take X-rays of the hip in the anteroposterior and lateral planes. Do not allow distraction of the fragments of a fractured femur.
	Shaft of the femur	Skeletal traction within first 24 hours sufficient to maintain reduction.	Thomas splint with traction, followed by plaster spica or walking brace.	16–24	
	Patella	Open operation if fragments are separated.	Posterior plaster splint or bivalved cast.	3–6	
	Condyles of tibia	If displaced, by open operation.	Posterior plaster splint or bivalved cast.	8–12	
FRACTURES OF THE LEG AND ANKLE	Shafts of tibia or fibula or both	Immediate; with traction and manipulation or open reduction and fixation of fragments by pin or plate.	Simple fracture: Plaster cast from upper thigh to toes. Complicated fracture: Skeletal traction with pin through os calcis or open reduction with internal fixation of fragments.	8–14	In a fracture dislocation of the ankle, restore the joint mortice so that the long axis of the tibia bisects at right angles the top of the astragalus An oblique fracture of the tibia with a fracture of the fibula will not maintain correct position without traction or internal fixation. Immobilize a Potts fracture in inversion with plaster. X-ray a fracture dislocation of the ankle after reduction to be certain that there has been no change in position or recurrence of deformity.
	Fracture dislocation of the ankle	Immediate; restoring the ankle mortice, under general anesthesia.	Plaster splint or cast; foot inverted for a Potts fracture, and in neutral position for others.	6–8	
	Fractures of external malleolus	None.	Walking plaster splint or cast from knee to toes.	3–5	

FRACTURES OF THE FOOT AND TOES	Os calcis	Immediate; break up impaction and restore tuber angle; skeletal traction with lateral compression in severely comminuted fractures.	Plaster cast from toes to knee. Incorporated skeletal traction pins when used with foot in plantar flexion.	12–16	Watch circulation in all badly comminuted and displaced fractures and dislocations. Do not allow too early weight-bearing in a fracture of the os calcis. Adequately support the longitudinal and metatarsal arches when weight-bearing with a shoe is allowed.
	Astragalus (fracture dislocation)	Open operation usually necessary.	Plaster with foot in slight plantar flexion.	12–16	
	Metatarsals	Manipulation and skeletal traction through phalanges.	Skeletal traction and plaster cast from toes to knee.	4–6	
	Phalanges	Usually necessary only in big toe, with traction through terminal phalanx.	Plaster splint or cast.	3–4	
FRACTURES OF THE SPINE AND PELVIS	Cervical spine	Without neurological changes: Traction with Sayre type head halter, using approximately 6 lbs. weight, neck in hyperextension. With neurological changes: Skeletal traction with Crutchfield tongs.	After traction, Calot or Minerva type plaster jacket; may be followed by cervical spine brace.	16–24	Do not move an injured dorsal or lumbar spine except in the prone position. Move an injured cervical spine only in the supine position with a support under the neck to maintain hyperextension. Record the presence or absence of damage to bladder and urethra in fracture of the pelvis. Hyperextension of the upper dorsal spine will not reduce a compressed fracture of the body of a vertebra. Do not perform a laminectomy for a spinal injury with cord damage unless there is X-ray evidence of a fragment of bone within the spinal canal or of progressive neurological changes. The back support for a fracture of the body of the lower dorsal or lumbar vertebra should not be removed in less than 12 weeks.
	Lower dorsal and lumbar spine — compressed fracture of body of vertebra	Without neurological changes: In hyperextension under anesthesia with pressure over the deformity to reduce prominence. With neurological changes: Gradual hyperextension on special fracture bed or frame.	Plaster body cast in hyperextended position from neck to pubis.	12–24	
	Pelvis	If complete and displaced upward: Traction to lower extremity of affected side. With dislocation of hip: Center skeletal traction downward on the lower extremity and lateral skeletal traction through the greater trochanters.	Broad pelvic hammock suspension followed by double spica.	12–18	
COMPOUND FRACTURES—GENERAL	All	Immediate; as indicated by specific fractures.	In padded plaster cast after (1) thorough irrigation and debridement of wound, (2) frosting of wound surfaces with sulfanilamide crystals, (3) lightly applying Vaseline gauze into wound, and (4) applying dry dressings over wound.	As indicated for specific fracture.	Do not immobilize the spine for a simple fracture of a transverse or spinous process. Do not allow weight-bearing in a complete fracture through the pelvis for 12 weeks. Do not scrub or shave surrounding skin without protecting the wound. Avoid washing foreign bodies into wound by superficial irrigation. Make incisions longitudinal and large enough to perform a complete debridement. Excise all damaged muscle tissue, but save skin. Apply internal fixation at time of debridement, if need for immobilization. Do not remove attached or large detached bone fragments. Pack wound loosely and do not suture. Do not be satisfied with less than complete immobilization.

Source: Shands, A. R., Jr.: *Suggested Therapy for the More Common Fractures and Dislocations.* Air Surgeon's Bull. 1: 12–13, July 1944.

rather than the comprehensive definition of a fracture, fixed all their attention on the injured bone.

Simple fractures in military practice generally presented substantially the same problems as in civilian practice and were treated by the same methods. Closed techniques were preferred, but open reduction was used on the proper indications. In a survey of 968 fractures and dislocations treated in six Army Air Forces hospitals in 1942 (selected merely because statistics from them were readily available), open reduction was employed in only 3.8 percent of the cases (*23*). The small proportion was taken to indicate satisfaction with the results achieved by simpler and safer closed methods.

Gunshot wounds that caused compound fractures were of two general types:

1. Wounds with large skin defects, widely exposed underlying structures, and full visualization. These injuries were practically always well treated initially. Debridement was adequate because the surgeon could see exactly what he was doing, and clostridial myositis and other infectious complications were infrequent.

2. Wounds with very small openings in the skin but with tremendous soft-tissue damage subcutaneously. To reach the exterior, the shell fragment (fragments) had to tear through ligaments and muscles as well as bones, and the effect often suggested that some powerful force was attempting to push the structures outward. Bits of clothing were often caught and pulled back into the wound. The greatest danger of a wound of this kind was that an inexperienced surgeon might not recognize the damage he did not see and might make his initial wound surgery superficial rather than extensive. In most cases, however, the significance of the findings was recognized, the opening was greatly enlarged, debridement was extensive, and all underlying devitalized and separated tissue and bone fragments were removed. As a result, clostridial myositis and other infectious complications were infrequent, just as in the more obvious type of wound.

Compound fractures, particularly infected compound fractures, often furnished major problems. The situation was enormously improved over that in World War I, but nonetheless a vicious circle was often encountered in which localized bone infection went on to sequestration, the infected bone and sequestra acted as local sources for further infection of the bone and surrounding soft tissues, and this infection, in turn, caused further degeneration and sequestration. The circle continued as long as sequestra were present or suppuration persisted. The objective of therapy was to break the vicious circle by eliminating or minimizing the wound infection while waiting sequestration and excision of the sequestra. The objective could be accomplished by a combination of antibiotic therapy and surgery, with sound surgery the more important of the two measures. Conversion of the compound open fracture into a simple closed fracture could be accomplished only by coverage of the wound with skin, since skin is the only tissue that can protect other tissues from infection, thermal change, and other trauma. The techniques employed must be based on physiologic principles, offer maximum restoration of function in the shortest possible time, be associated with the least risk, and be as simple as possible.

To accomplish these results often meant many months of hospital care while planned reconstructive surgery was carried out. It was not often possible to return patients with such injuries to duty, but, though they could not again withstand the stress of military service, they could usually be rehabilitated for active and useful civilian lives.

That lives were saved, limbs were spared, the time consumed in treatment greatly reduced, and the ultimate results enormously improved in infected compound fractures in World War II can be attributed to a number of factors, including

1. Early, adequate initial wound surgery, expedited by adequate measures for speedy transportation to forward hospitals.
2. The liberal use of plasma, within its indications, and blood transfusion (*18*).
3. The availability of, first, the sulfonamides and, later, penicillin (*24*).
4. The performance of competent, definitive surgery in the Zone of Interior.
5. The development of an efficient system of reconditioning and rehabilitation.
6. The improvement in medical education, and the development of interest in fracture problems, between World War I and World War II. The physicians who entered service in World War II were generally better trained, and if they were orthopedic surgeons, they were specifically better trained, for these reasons.

Orthopedic surgeons, especially those newly inducted from civilian life, frequently were highly critical of the uniform and standardized techniques which they were required to follow. Standardization was sometimes undesirable, it is true, but it was nonetheless essential for a number of reasons: the necessity for managing patients by military echelons; the lack of previous military experience of even highly qualified civilian surgeons when they came into service; the risk of permitting individual preferences in military circumstances; and the seriousness of combat-incurred fractures, especially fractures of the femur, as compared with the general run of civilian fractures. The general and orthopedic surgeons who cared for casualties with combat fractures during the war emerged from it knowing far more about these injuries than when they went into service. They had much to teach civilian surgeons and medical students. On the other side of the picture, the civilian who had been in service and had sustained a fracture would in the future expect far better treatment, if he sustained another in civilian life, than he would have settled for before the war.

REDUCTION OF FRACTURES UNDER FLUOROSCOPY

As late as 1944, some hospitals were still employing the highly dangerous technique of reduction of fractures under fluoroscopy. This was a prac-

tice that had never been encouraged and was no part of official fracture policy. In War Department Technical Bulletin (TB MED) 22, dated 21 March 1944 (*25*), it was specifically discouraged, but, oddly, it was not forbidden, as it should have been. It was pointed out in this bulletin that this technique is one of the most dangerous possible uses of X-rays and would inevitably result in damage to the hands of the surgeons who used it, with subsequent disability claims, if it were allowed to continue. It was, therefore, recommended that lead-impregnated gloves be worn during the entire procedure whenever this technique was used.

It was also noted in this bulletin that reduction of fractures under fluoroscopic control was unnecessary since arrangements could easily be made in any hospital for rapid processing of roentgenograms near the operating room; they could be ready for the surgeon's inspection within 2 or 3 minutes after they were taken.

SELECTION OF TECHNIQUES

As has been mentioned elsewhere, judgment was needed in the selection of types of therapy suited for special cases. This was particularly true of injuries in which long-continued treatment would be necessary and there was serious doubt as to the outcome. It was futile, for instance, to undertake a clearly hopeless battle to conquer a severe chronic infection in a badly damaged lower extremity when amputation, with the fitting of a prosthesis, would eliminate the infection, restore the patient to normal health in a relatively short time, and give him a more serviceable extremity than he would have had with more conservative treatment. Sometimes, the best plan was to let the patient decide whether he would take his chances with prolonged therapy, with a poor ultimate prognosis, or would prefer amputation and a prosthesis at once.

The situation was, of course, different when the upper extremity was involved. Even in the most severe injuries, if circulation was adequate to distal points and hope existed for sensation distally, every endeavor to save the limb was worthwhile.

The following history is an illustration of the kind of problem orthopedic surgeons were sometimes faced with during the war:

Case 1.—A casualty was admitted to a Zone of Interior hospital with a severe infection originating in a compound, comminuted fracture of the upper third of the shaft of the right femur; a 6-inch loss of bone in the shaft; irreparable damage to the sciatic nerve; and a compound, comminuted fracture of the knee, in which function obviously could not be restored. The patient's condition on admission was very poor, but, after 3 weeks of multiple transfusions, penicillin, and other adjunct therapy, he tolerated sequestrectomy well. Amputation was then recommended; he could not have tolerated it on admission. It was believed that, in spite of his improved status, morbidity would be dangerously increased if an attempt should be made to obtain wound healing and then perform a plastic procedure and bone graft. Furthermore, even if these operations should be successful, they would accomplish nothing for the sciatic nerve was

irreparably damaged, the knee joint would be permanently stiff, and very little function of the hip joint could be anticipated. The surgery necessary to achieve even these poor results would take many months, whereas amputation, revision of the stump, and fitting of the prosthesis could be accomplished in a much shorter time.

The patient, when presented with the arguments for immediate amputation, accepted the recommendation, and his recovery in an amputation center was as smooth as had been hoped for.

PREVENTION OF INFECTION

The prevention of infection in compound fractures was far simpler, and far more successful, in World War II than in World War I. Good surgery, excellent adjunct therapy, and the availability and effectiveness of antibiotic agents were the basis of the good results. Well-run orthopedic services, however, did not forget the simpler precautions, and the routine used at Halloran General Hospital, Staten Island, N.Y., was more or less duplicated at all other hospitals:

1. Soiled bed linen was bagged as it was removed and was never, under any circumstances, thrown on the floor.
2. In wards housing patients with open wounds, dressings were deferred for at least an hour after beds had been changed and the floors swept.
3. While wounds were being dressed, traffic in the ward was reduced to a minimum and patients remained by their beds.
4. All personnel participating in the dressings were always masked. Whenever possible, officers and their assistants who had sore throats or infections of the hands or fingers were relieved from doing dressings.
5. Patients with open wounds and upper respiratory infections were masked during dressings.
6. Clean wounds were dressed first and the most severely infected wounds last.
7. A fully equipped dressing cart was on hand, with competent assistants, before dressings were begun.
8. Before dressings were begun, the surgeon or ward officer who was to handle them scrubbed his hands for 6 minutes, just as he would before an operation.
9. Bandage scissors, which were usually contaminated, were used only for the removal of bandages.
10. Forceps were used to remove and apply dressings, and all manipulations were carried out with them and with hemostats and scissors, so that the hands never touched the wound. With this technique, it was not necessary to wear gloves.
11. All soiled dressings, crusts, extruded foreign bodies, bits of tissue, and other material removed from the wound were placed at once in a suitable covered container and disposed of later by a standard routine.
12. Suppurating wounds were irrigated with physiologic salt solution. The original practice of placing crystalline sulfanilamide in the wound was abandoned by the middle of 1943 (p. 445).
13. All containers, arm baths, urinals, bedpans, instruments, blankets, linens, and other items that had been in contact with infected wounds were sterilized as soon as they had been used.
14. If a plaster cast became contaminated with infectious material, it was changed unless there was some serious contraindication. Antiseptic washes were considered useless.
15. Wounds were not dressed merely because the dressings were moist from serum.

Repeated dressings created opportunities for contamination and were carried out only as indicated.

16. If dressings had to be removed in the X-ray or physical therapy departments, it was the responsibility of the ward officer to remove and replace them.

EXTERNAL FIXATION

External fixation of fractures, by the Roger Anderson, Haynes, Stader, and similar techniques, was used in the first months of the war, though not very generally, and by October 1943, this method had been almost entirely abandoned. No matter what apparatus was used, external fixation gave poorer results than any other technique. It was also potentially dangerous for a number of reasons, including infection around the pinholes, nonunion from distraction of the bone fragments, and severe reactions in the bones from electrolysis. When all the apparatus for it was recalled by The Surgeon General, some orthopedic surgeons, who were trained in its use and had personally achieved good results with it, thought the ruling unnecessarily radical. Eventually, there was general agreement that this was not a safe method to put into the hands of those without previous experience with it.

BALANCED SUSPENSION SKELETAL TRACTION

The official policy on balanced suspension skeletal traction that had been in effect in the management of fractures throughout the war was officially set forth in TB MED 133, issued in January 1945 (*26*). This bulletin called attention to the value of this form of treatment, especially in fractures of the femur, and to the importance of using a simple, standard technique, with standard items of equipment. Acceptable sites of application were shown diagrammatically (fig. 92).

The substance of this bulletin, which is almost entirely devoted to fractures of the femur, is discussed under that heading (p. 377).

When patients with fractures of the femur were received from overseas in plaster, traction was instituted routinely in most hospitals. It was applied to fractures of the tibia and fibula according to the indications of the special case, but was seldom applied to the humerus. It was particularly important to institute traction suspension without delay in all suitable fractures in which union was not solid or in which shortening and deformity were evident. Casts were used instead of traction in some instances of osteomyelitis of the lower third of the femur, when the knee joint was so involved in the process that motion could not be anticipated and the risk of nonunion transcended all other considerations.

In some hospitals, even when fractures were received united, it was the practice to place them in balanced suspension skeletal traction so as to stimulate activity and gradually institute motion in the joints.

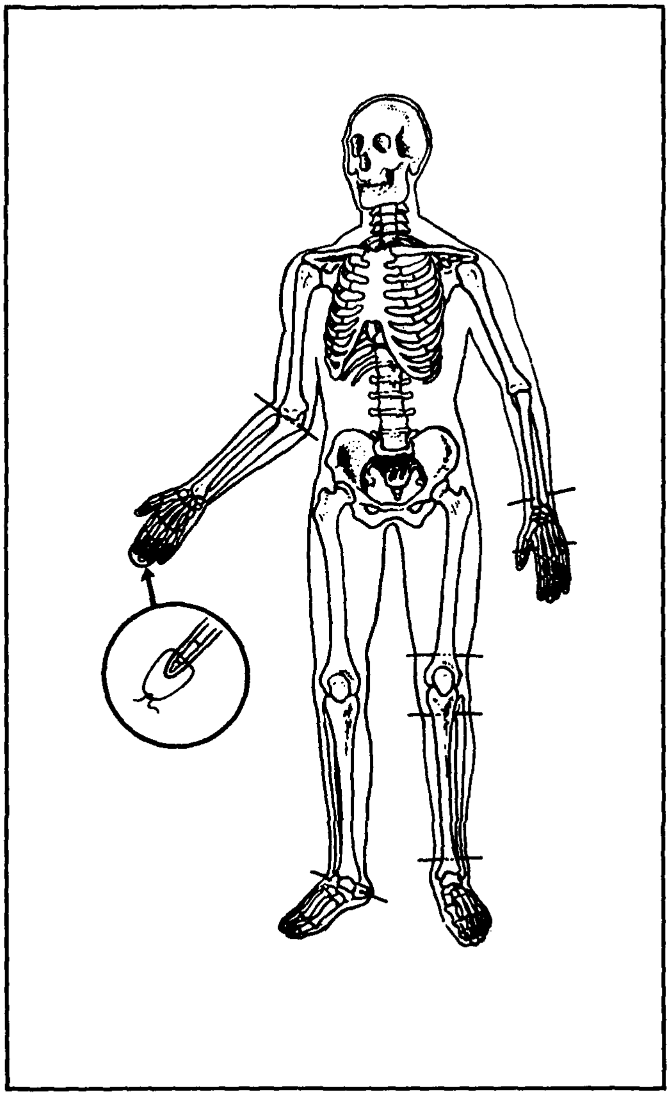

FIGURE 92.—Acceptable sites for application of skeletal traction. (War Department Technical Bulletin (TB MED) 133, January 1945.)

COMPRESSION DRESSINGS

Compression dressings were used both before and after operation, with excellent results. They were applied voluminously immediately after operation and, if necessary, several plaster reverses were added for additional stability. The extremity was then suspended in a Thomas splint and left undisturbed for 10 days. When the dressings were removed, for removal of the sutures, the absence of edema was usually most gratifying, and it was then a simple matter to apply a skintight cast and secure excellent immobilization. It should be emphasized, however, that while immobilization was good with these dressings, they were applied primarily to prevent edema. They were particularly useful in hand injuries, in open reductions,

in bone grafts, in operations on the joints, and in plastic procedures. It was interesting to observe their value in patients transferred from other hospitals, in poor nutritional status and with edema of the extremity so marked as to prejudice the success of any surgical procedure. It was remarkable what a few days of suspension in compression dressings could achieve in preoperative preparation.

MANAGEMENT OF INFECTED COMPOUND FRACTURES

Classification

Efficiently run orthopedic services developed routines of management for infected compound fractures according to the categories of injury and infection which they represented. In spite of the enormous improvement in the condition of the casualties received from overseas in World War II as compared with the status of those received in World War I, it was inevitable that a certain proportion of these combat fractures should be infected.

At Halloran General Hospital, with its large debarkation service, it was found practical to use the following classifications:

1. Septic compound fractures uniting in satisfactory alinement and length. These fractures furnished no problem provided that drainage was adequate, sequestra were excised, and the wound was kept open and allowed to heal from its depths. Balanced suspension skeletal traction was used in almost all fractures of the femur. Other fractures were managed in plaster.

2. Septic compound fractures still un-united but with satisfactory alinement and length. When these fractures were managed like group 1 fractures, the majority progressed to wound healing and bony union.

3. Septic compound fractures still un-united and with roentgenographic evidence of unsatisfactory reduction. They often furnished serious problems. If the fracture involved the shaft of the femur and was not of too long duration, it could usually be reduced by traction. Skin traction was preferred, but skeletal traction through the upper tibia was used when this technique was indicated. Skeletal traction through the distal femur was seldom used unless the compound wound was over the upper femoral shaft; even then, it was instituted only when the infection was mild.

Fractures involving the shaft of the humerus also were handled by traction, preferably by a well-applied hanging cast. Sequestrectomy was usually deferred until bony union was sufficient for support to be discontinued.

Compound fractures of the leg (p. 697) and the forearm (p. 561) furnished the most serious problems in this group. They were often severely comminuted, and drainage or removal of devitalized fragments of bone was necessary after sequestrectomy. In selected cases, an attempt was made to reduce the fracture at the same time that the surgery just described was done. Neither internal nor external fixation was employed, but skeletal traction was occasionally used to maintain reduction, though plaster was preferred unless the femoral shaft was involved.

4. Septic compound fractures with union but in positions incompatible with satisfactory function. Infection was not usually a serious problem when these patients were received, but it had often been serious overseas and was usually the explanation of the unsatisfactory reduction. Surgical correction was not attempted until after

complete clearing of the infection. The deformity was corrected by osteotomy, followed by bone grafting and, in many cases, by internal fixation.

5. Septic compound fractures with nonunion. The solution in these cases was grafting, but not until a considerable period after wound healing.

6. Septic compound fractures associated with loss of bone, loss of soft tissue, or loss of both. These fractures also presented extremely serious problems. They were handled by plastic surgery, preferably performed by a plastic surgeon, followed by reconstructive bone surgery with bone grafting. In some of these cases, amputation would probably have been the wisest course. In an occasional case, a Vitallium replacement was used with good results. When loss of substance involved a weight-bearing joint, fusion was performed.

7. Septic compound fractures associated with established chronic osteomyelitis. Drainage, sequestrectomy, and removal of foreign bodies were the standard procedures, with saucerization as indicated (p. 309). In some cases in this group, persistent drainage from a sinus over a compound fracture was attributed clinically to chronic osteomyelitis. Roentgenographic examination did not confirm the diagnosis, and drainage persisted even when fracture healing occurred. It was found in these cases that the drainage was the result of adherence of abundant scar tissue to underlying bone; it ended as soon as the sinus and the scar tissue were excised and the bone was covered with healthy skin. The orthopedic staff believed that the same explanation might hold for other cases erroneously diagnosed as chronic osteomyelitis, which were really nothing more than infected scar tissue that did not heal because of impaired circulation.

Principles of Management

The therapy of infected compound fractures varied with (1) the virulence of the infecting organism; (2) the timelag since injury; (3) the patient's general health and well-being, particularly his resistance; and (4) the degree of damage to bones and adjacent soft parts. A stimulating dose of tetanus toxoid was repeated before any surgical procedure. With the other modalities available to the World War II orthopedic surgeon, particularly the antibiotics, plasma, and whole blood, the poor surgical risk could be rather quickly brought to optimal condition for surgery. It had been expected that, with the use of penicillin, flareups of infected fractures after surgery would be considerably reduced, but this hope was not entirely fulfilled.

The routine of management in infected compound fractures at Halloran General Hospital was much the same as that in other hospitals that received casualties from overseas:

1. If the patient was in poor general condition, the first attention was devoted to its improvement by various adjunct measures described in detail under that heading (p. 441).

2. Until the patient's improvement permitted surgery, the first principle of wound management was the provision of ample opportunities for drainage. The wound was irrigated at regular intervals, and was packed loosely with petrolatum-impregnated gauze to prevent closure and facilitate drainage.

3. Sequestra and devitalized bone fragments were removed as soon as the patient was regarded as able to tolerate the procedure.

4. If the fragments were overriding, some operation to correct the malposition was carried out. The important consideration in the selection of this and other procedures was not how the patient would be treated in a civilian hospital but how he could best be treated under existing circumstances.

5. Immobilization was accomplished by padded plaster casts except in fractures of the femur, which were treated by traction. Little padding was necessary unless the patient was so emaciated that the bony prominences were exaggerated. The timing of changes of the cast depended upon the severity of the infection and the amount of drainage. The use of windows for dressing purposes was not favored.

6. From the very beginning of treatment in Zone of Interior hospitals, there was emphasis on contracting the muscles and moving the joints (p. 275). Exercises of various kinds could easily be performed with the extremity in plaster.

SERIAL STUDIES OF INFECTED COMPOUND FRACTURES

Three series of infected compound fractures, 143 in all, were studied by Capt. Richard S. Dodge, MC, from Cushing General Hospital, Framingham, Mass. (*27*). Of these, 75 patients were treated by the method introduced by Maj. Champ Lyons, MC, at Halloran General Hospital (*24*) (p. 451), 19 by catheter irrigations, and 49 by the Smith-Petersen technique. The cases were essentially similar except for the method of management:

1. All the patients were young, previously healthy men.
2. All had chronically infected compound fractures, almost all of which had been sustained in combat.
3. Early care had generally followed the directives for management of combat injuries.
4. The duration of infection ranged from 6 weeks to 15½ months.
5. A number of the patients had other injuries, but in all cases, the injuries of the extremities were the most serious wounds.
6. All the patients were treated by a single surgeon, which insured uniformity of control.

Series 1.—Preoperative preparation in the 75 patients treated by the Lyons method consisted of transfusions of plasma and whole blood; a high-caloric, protein-rich diet; supplemental vitamins; wound cultures and penicillin-resistance tests on gram-positive organisms as indicated; and frequent changes of dressing, to prevent excessive accumulation of purulent exudate.

Many of these fractures were so badly comminuted that when sequestrectomy was performed, it was impossible to determine the number of fragments removed. Enough bone and soft tissue were resected to insure freshly bleeding surfaces on every aspect of the wound. The residual cavity was packed with penicillin-impregnated gauze and sealed with a layer of petrolatum-impregnated gauze and dry dressings. The extremity was put up in plaster or in traction-suspension.

Postoperative care, in addition to standard measures, consisted of dressings daily or on alternate days, as necessary, under rigid sterile precautions, with irrigations of physiologic salt solution or hydrogen peroxide solution, to remove loose detritus. They were continued until the infection was controlled and the wound surfaces completely covered with new epithelium. Systemic penicillin, which had been begun 24 hours before operation, was continued for 13 days after operation.

The criterion of success in this group of cases was complete epithelization of the wound within 16 weeks. By this criterion, there were 46 successes in the 75 cases, with nine recurrences. The average time of closure was 9.4 weeks. The remaining wounds closed in from 7½ to 12 months and the cases were listed as failures.

Series 2.—Preoperative preparation in the 19 cases managed by the catheter method was the same as described for the first series. Surgery consisted of excision of grossly infected bone and soft tissue, excision of scarred tissue, and sinus tracts, and sequestrectomy. The surgeon who elected to use this technique had to select his patients very carefully, bearing in mind that closure of the surgical wound was part of the procedure.

After the wound had been irrigated with physiologic salt solution, a small soft rubber catheter was inserted down to the base of the wound. Then, the muscle and fascia were closed with interrupted catgut sutures, and the skin edges were approximated with interrupted black silk sutures. The catheter was held in position by a single skin suture. By wide undermining of the skin or the use of relaxing incisions, it was possible to close many wounds in which areas of scar and granulation tissue were extensive.

Postoperative treatment, in addition to standard measures, included irrigations of the wound through the catheter with penicillin solution every 4 hours. The skin about the incision during this period was protected with a bland ointment. The overflow from these instillations and the accumulated drainage from the wound required that the dressings be completely changed every 3 or 4 days.

As soon as drainage appeared to be decreasing in amount and the dressings were chiefly saturated with the overflow penicillin solution, the catheter was removed, usually between the seventh and the 12th day. Dry dressings were then used as long as any drainage persisted.

In this series, the criterion of success was complete closure of the wound within 12 weeks. In the 19 cases handled by this technique, 14 wounds were completely closed within this period, on an average of 25.5 days. There were no known recurrences. The remaining wounds closed in from 6½ to 10 months.

In spite of the success of this technique, it was not based on sound surgical principles, and the criterion of success, closure of the wound within 25 days, was not considered sufficient to justify its continued use. Also, the exact time at which the catheter was removed was based on dubious grounds—the gross appearance of the wound, the amount and type of irrigating fluid returned, and the patient's clinical status and white blood cell count and sedimentation rate. After the catheter was removed, another undesirable feature was present: The underlying wound cavity was connected to the skin by a small sinus tract (creating what was, in effect, an ink-bottle space), and it was thought probable that during the process of closure the cavity might become sealed at some point along this sinus tract and might not fill in gradually from its base. The chances of later recurrence were clear, and this method was discontinued.

Series 3.—Meantime, as experience increased, certain principles of management evolved:

1. Wound must be cleared of as much necrotic bone and soft tissue as possible under direct visualization at operation.
2. Purulent drainage after operation can be reduced by early use of penicillin locally and systemically.
3. After a brief period in which infection would be controlled by the combination of surgery and penicillin just described, reestablishment of the local circulation would tend to assure permanent healing.
4. Early wound closure, with the obliteration of dead space, not only would insure early reestablishment of the local circulation but also would reduce the chances of additional contamination.

At the suggestion of Dr. Marius N. Smith-Petersen, civilian Consultant in Orthopedic Surgery, First Service Command, a third series of 49 cases was managed by a technique which incorporated the principles just stated:

The usual preoperative preparation was employed. Penicillin by the intramuscular route was begun 24 hours before operation and continued for 6 days afterward.

The surgical incision was so placed as to eliminate as much of the existing scar as possible and still permit closure of the wound. This requirement limited selectively the cases in which this technique could be used. The infected fracture site was widely exposed and all necrotic and poorly vascularized tissue was removed, leaving freshly bleeding tissue in all portions of the cavity. The wound was then thoroughly irrigated with physiologic salt solution, and two irrigating tubes were placed in the cavity and allowed to protrude above the skin edges. The wound was closed in layers. The choice of irrigating tubes was limited by the supply at hand. After using all the supply of Smith-Petersen Vitallium catheters, soft rubber catheters were used.

When the patient was returned to his bed, one irrigating tube was attached by rubber tubing to a drainage bottle under the bed. The other was either connected with an overhead penicillin reservoir apparatus or covered with gauze, clamped, and placed below the top layers of the dressings. Local instillations of penicillin solution were begun at once and were repeated every 4 hours. Unless excessive drainage required a change of dressings, the wound was not examined for 6 or 7 days. Then alternate skin sutures were removed, and the others were removed 2 days later.

The patient was scheduled for definitive surgery as soon as (1) there was no visible local tissue reaction, (2) the amount of purulent drainage that accumulated between irrigations was minimal, and (3) the irrigating fluid returned apparently consisted chiefly of penicillin solution. Systemic penicillin was begun the day before operation and continued for 6 days afterward.

The second operation consisted of excision of the scar of the first-stage operation; exposure of the fracture site; exploration of the wound to search for residual bone fragments and necrotic tissue; removal of the irrigating tubes; and closure of the wound in layers, with the introduction of a small whisk drain if necessary. Dressings were changed within the week after operation only if it seemed necessary.

Closure within 12 weeks was considered the criterion of success in this group, and 43 of the 49 cases were thus classified. There were two known recurrences. In these recurrences, as well as in three of the failures, infection occurred after internal fixation in which iliac or tibial bone chips were used.

The experience in this third group showed that wounds with comparatively small skin or other soft-tissue defects were amenable to the two-

stage procedure just described. Thorough sequestrectomy and early reestablishment of a competent local circulation were of prime importance. The second stage operation permitted further exploration of the wound and assured firm closure with obliteration of dead space.

It was fully realized that observation of all these 143 patients over a period of years would be necessary before the real results of this or any other technique could be evaluated.

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CHAPTER XI

Splints, Bandages, and Appliances

Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

HISTORICAL NOTE

Splints and other appliances used by the U.S. Army Medical Department in World War I were not standardized until late in 1917 (*1*). A board appointed by General Headquarters, American Expeditionary Forces, to report on the advisability of their standardization recommended on 9 September 1917 that a manual on the subject be prepared for the use of medical officers. Six weeks later, the manual whose preparation had been recommended was delivered to supply depots in France. The printing of the manual, as well as the manufacture and procurement of the splints and other appliances, was the responsibility of the American National Red Cross (*2*).

SPLINTS AND SPLINTING

Manuals

FM 8–50.—The methods of splinting described in the 1918 manual naturally were somewhat modified as time passed, but no official changes were made until War Department Field Manual 8–50, entitled "Splints, Appliances, and Bandages," was issued on 11 September 1940 (fig. 93) (*3*). The policies which it set forth were those in effect concerning splinting when the United States entered World War II, 15 months later. This manual was intended chiefly for medical officers to use in the instruction and training of enlisted men. It was written in detail and profusely illustrated, but was meant to be supplemented by demonstration and practice.

The splints described for transportation, some of which were also used for definitive care, consisted of:

1. The army hinged half-ring thigh and leg splint, with the adjustable traction strap and the support and foot rest (fig. 94).
2. The Thomas hinged arm splint.
3. Basswood splints for the upper extremity.

Apparatus described for definitive management of fractures included:

1. Splints of plaster of paris for closed reduction.
2. Apparatus for traction by the weight-and-pulley method.

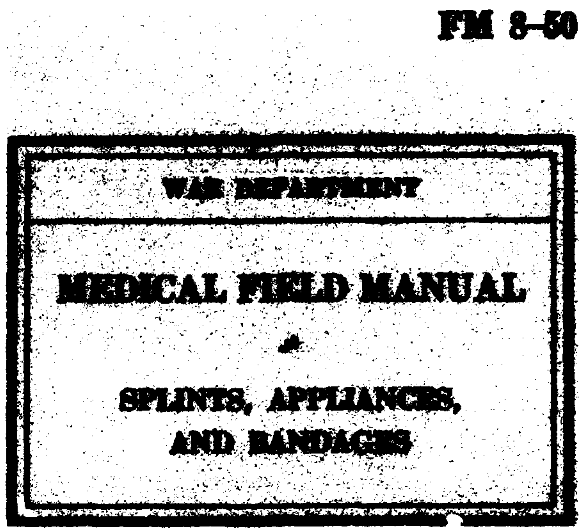


FIGURE 93.—Title of FM 8-50, 1940 edition.

3. Material for internal fixation.
4. The Balkan frame.
5. Apparatus for skin traction in abduction in fractures of the humerus.
6. Apparatus for insertion of Steinmann's pins.
7. Apparatus for skeletal suspension and traction.
8. Apparatus for the introduction of wires.
9. The Pierson attachment to the army hinged half-ring leg splint.
10. The Cabot's splint for immobilization of the leg, ankle, and foot.
11. The aluminum cockup splint for the wrist.
12. The airplane (abduction) splint (nonstandard and to be made locally) for the shoulder and upper extremity (fig. 95).
13. The T-splint for fractures of the clavicle (also nonstandard and to be made locally).
14. Basswood and other splints for the forearm.
15. Apparatus for hyperextension body casts (nonstandard and to be made locally).
16. Apparatus, including skull tongs, for fractures and dislocations of the cervical spine.

First aid dressings were also illustrated in this manual.

A revised edition of FM 8-50, entitled "Bandaging and Splinting" (fig. 96), was issued on 15 January 1944 (*4*). It had the same purposes as the earlier manual and, like it, was written in detail and profusely illustrated. Much emphasis was put upon standardization of techniques.

The splints described in the 1944 manual were fewer and less complicated than those in the earlier manual. They included:

1. The army hinged half-ring leg splint (fig. 97).
2. The wire ladder splint for the lower extremity.
3. The Thomas hinged arm splint.[1]

[1] The Thomas hinged arm splint was seldom used in the European theater to transport soldiers with gunshot fractures of the humerus. If traction was employed, the ring in the axilla tended to impede circulation to the extremity. The hanging cast and sling, or the shoulder spica of plaster of paris, was found to be safer and more effective.—M. C.

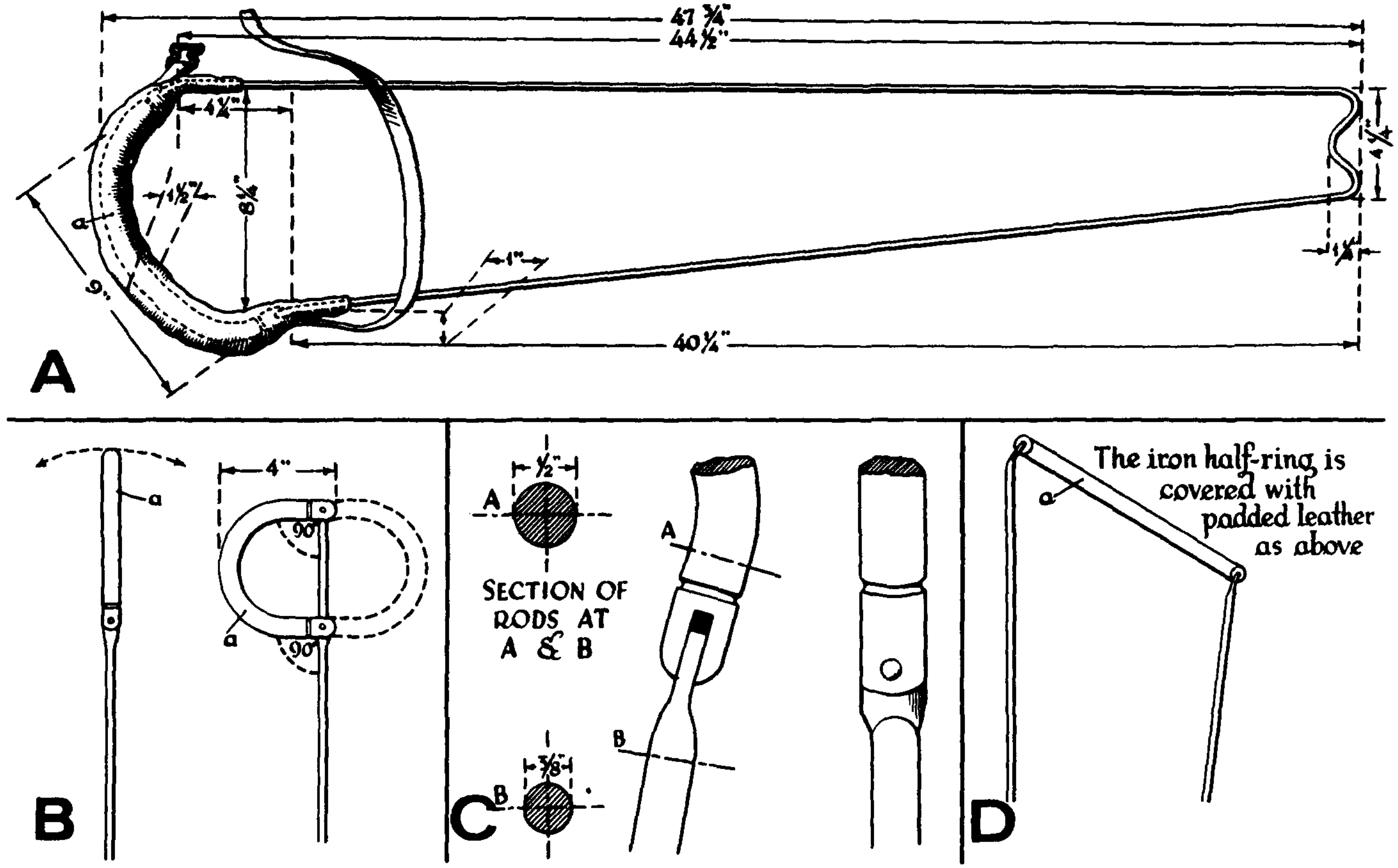


FIGURE 94.—Army hinged half-ring thigh and leg splint (FM 8–50, 1940). A. Anterior view. By turning the half ring on .ts swivels to right or left, the splint can be adapted for use on either leg. B. Lateral view. C. Detail of hinge. D. Splint in normal position, ready to receive right leg.

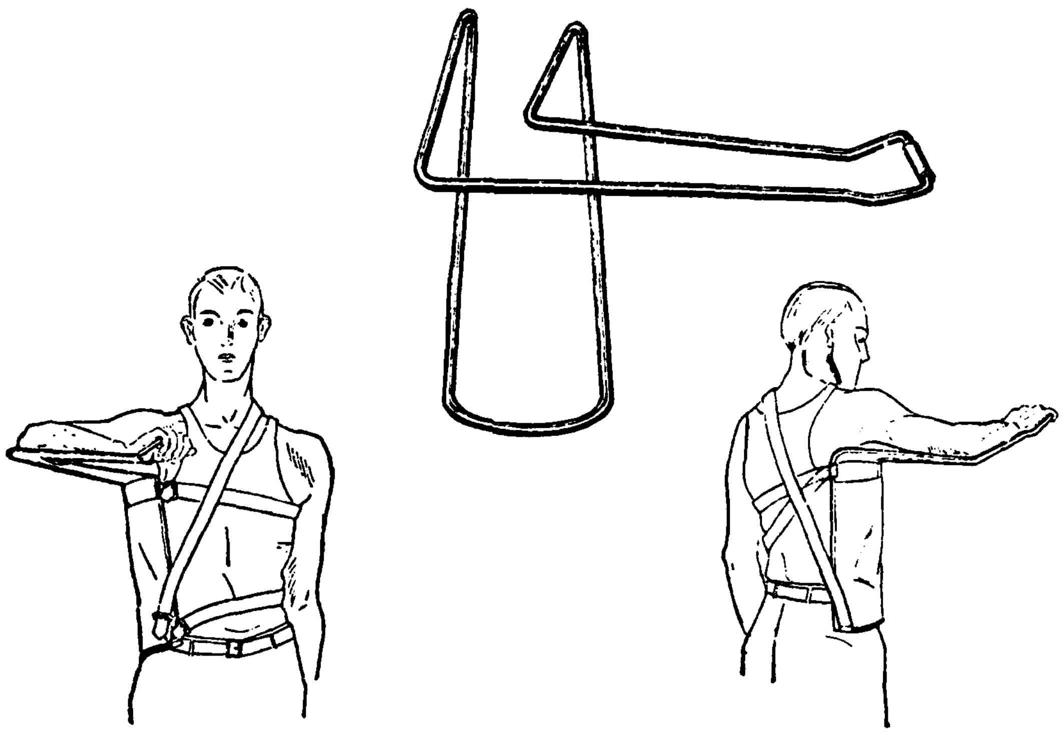


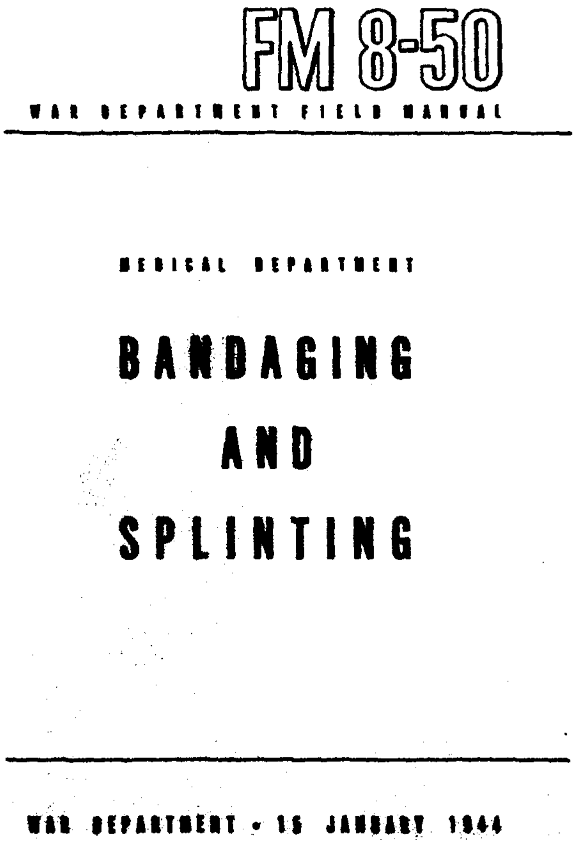
FIGURE 95.—Technique of applicat.n of airplane splint (FM 8-50, 1940).

4. The board splint for fractures of the humerus (fig. 98).
5. Basswood splints for fractures of the forearm, wrist, and hand.
6. The stick splint for fractures of the forearm or wrist.
7. The Balkan frame.

A number of improvisations were illustrated in this manual, and litter transportation for fractures of the spine was described in detail.

TM 8-220.—War Department Technical Manual 8-220, entitled "Medical Department Soldier's Handbook" and issued on 5 March 1941 (*5*), was the successor to an uninterrupted line of technical handbooks prepared by the Medical Corps and in use for more than 50 years. In this manual, the first to be published by the War Department for the information of enlisted personnel, much of the material, including the title, was borrowed from the earlier handbooks.

The material on splinting for fractures in this text was concerned chiefly with improvised methods and materials. Pieces of tin or wire mesh, for instance, were recommended for support of a broken leg or arm, with pillows, blankets, or even newspapers used for padding. Several precautions were recommended: The splint should be made as wide as the limb and long enough to immobilize the joint at either end. It should be tied on loosely to allow for swelling of the part. Finally, the condition of the extremity should be determined every 20 minutes, to make sure that the circulation was not becoming obstructed.


FM 8-50

WAR DEPARTMENT FIELD MANUAL

MEDICAL DEPARTMENT

BANDAGING AND SPLINTING

WAR DEPARTMENT • 15 JANUARY 1944

FIGURE 96.—Cover of FM 8–50, 1944 edition.

TM 8–210.—War Department Technical Manual 8–210, entitled "Guides to Therapy for Medical Officers," was issued on 20 March 1942 (*6*). It began with the maxim, *"Splint where they lie,"* and it emphasized the importance of applying splints before the period of spasm ensued, during which bone fragments could be driven into the soft tissue with resulting pain and shock. The apparatus described included:

1. The hinged half-ring leg splint.
2. The Murray-Jones traction splint for fractures of the upper extremity.
3. The padded board coaptation splint for fractures of the wrist and hand.
4. The wire-ladder splint for fractures of the ankle and foot.
5. Improvised splinting for fractures of the spine, cervical spine, and pelvis.

It was noted that detailed information concerning the construction and application of these splints was contained in FM 8–50, 1944 (*4*).

Other Publications

The Army Medical Bulletin for October 1942 (*7*) published a description of the various splints that had been used at Walter Reed General

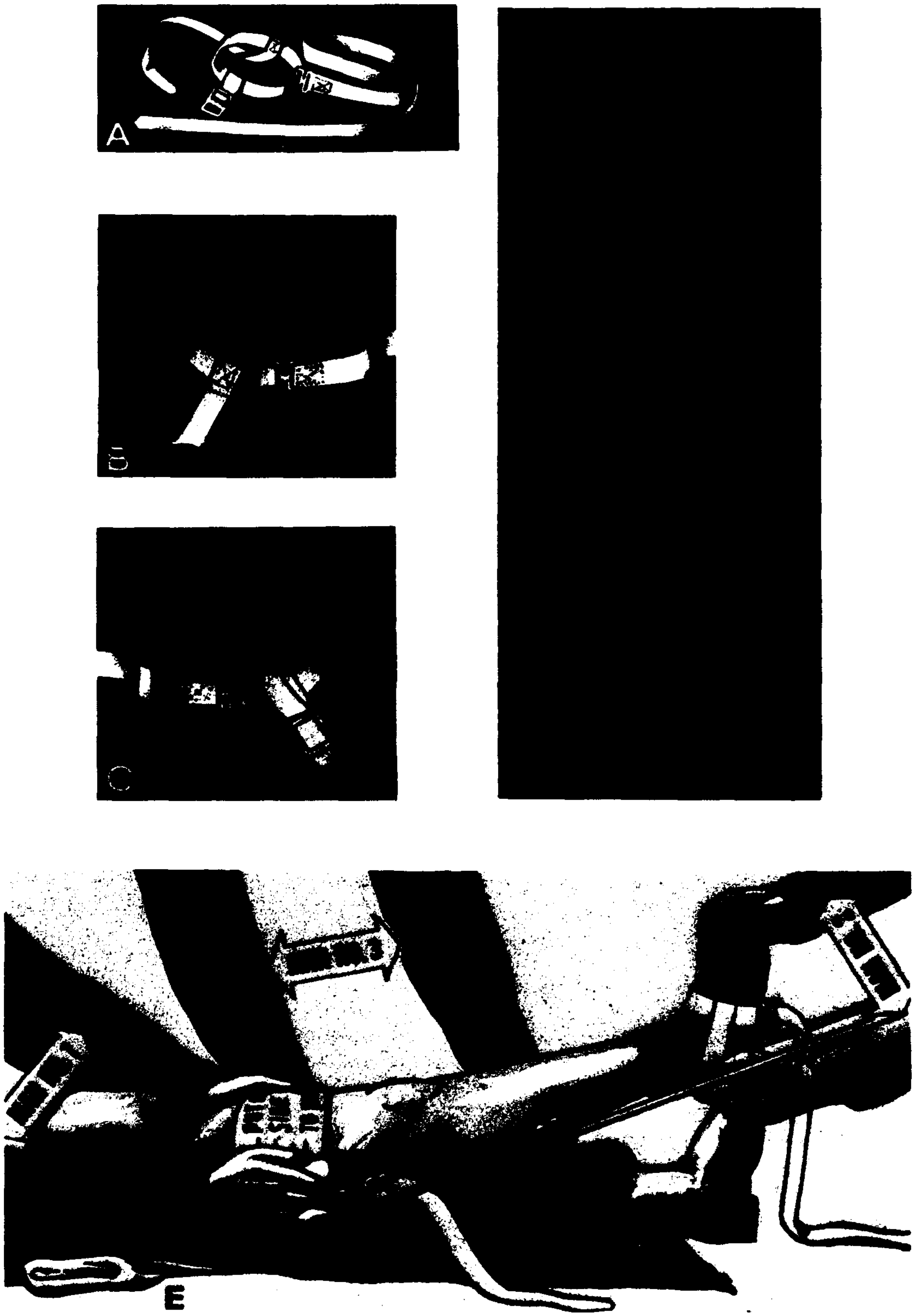


FIGURE 97.—*See opposite page for legend.*

Hospital, Washington, D. C., since 1919 and that were manufactured in the orthopedic shop there, with certain improvements as time had passed. The well-illustrated article, prepared by Col. (later Maj. Gen., The Surgeon General) Norman T. Kirk, MC, and Lt. Col. (later Col.) Leonard T. Peterson, MC, included descriptions of the following items, with brief notes on their use and on special features connected with them:

1. The ischial caliper, the only completely weight-bearing brace available for the lower extremity.
2. The tibial caliper. This device, which was used among other functions, to prevent fractures after grafts from the tibia, was not a weight-bearing splint.
3. The Taylor back brace.
4. The Thomas collar.
5. The wire drop foot splint.
6. The T-splint for fractures of the clavicle.
7. The aeroplane (abduction) splint for the shoulder and upper arm.
8. The crutch splint for fractures of the clavicle.
9. Arch supports (p. 801).

The Army Medical Bulletin for April 1943 (*8*) contained additional material on splinting prepared by the Subcommittee on Orthopedic Surgery, Division of Medical Sciences, National Research Council. The major portion of the presentation dealt with the management of casualties who must be transported either immediately or within a very short time after injury. Principles rather than special techniques were stressed. Optional methods were provided in many instances, in the realization that the handling of an individual patient would often depend largely on individual professional judgment. Among these considerations were the military situation; the materials, facilities, and personnel available at the place at which the splinting was to be done; and the anticipated time and nature of future transportation. Precautions to avoid injury from the techniques employed were also listed, with particular emphasis on the avoidance of pressure over the bony prominences.

Recommendations for the management of simple fractures were as follows:

Clavicle: A figure-of-eight bandage around the shoulders, crossing over the spine, with a sling at the wrist.

Shoulder: After reduction of the dislocation by traction at about 10–15 degrees of abduction, immobilization by a double sling (triangular bandages).

FIGURE 97.—Technique of application of traction strap for combat wound of right thigh (FM 8–50, 1944). A. Traction strap. B. Traction strap applied over shoe. C. Same, opposite side of foot. D. Army hinged half-ring leg splint. E. Man No. 1 has already placed splint alongside injured (right) leg, with ring near hip and buckle on outside. Man No. 2 passes hand through rods, grasping heel with that hand and grasping instep with other. He then exerts traction on foot, at the same time raising it several inches from ground. Man No. 1 then slips splint under leg, with buckle and longer rod on outside. During this procedure, Man No. 3 supports leg. After splint is applied, Man No. 1 dresses wound.

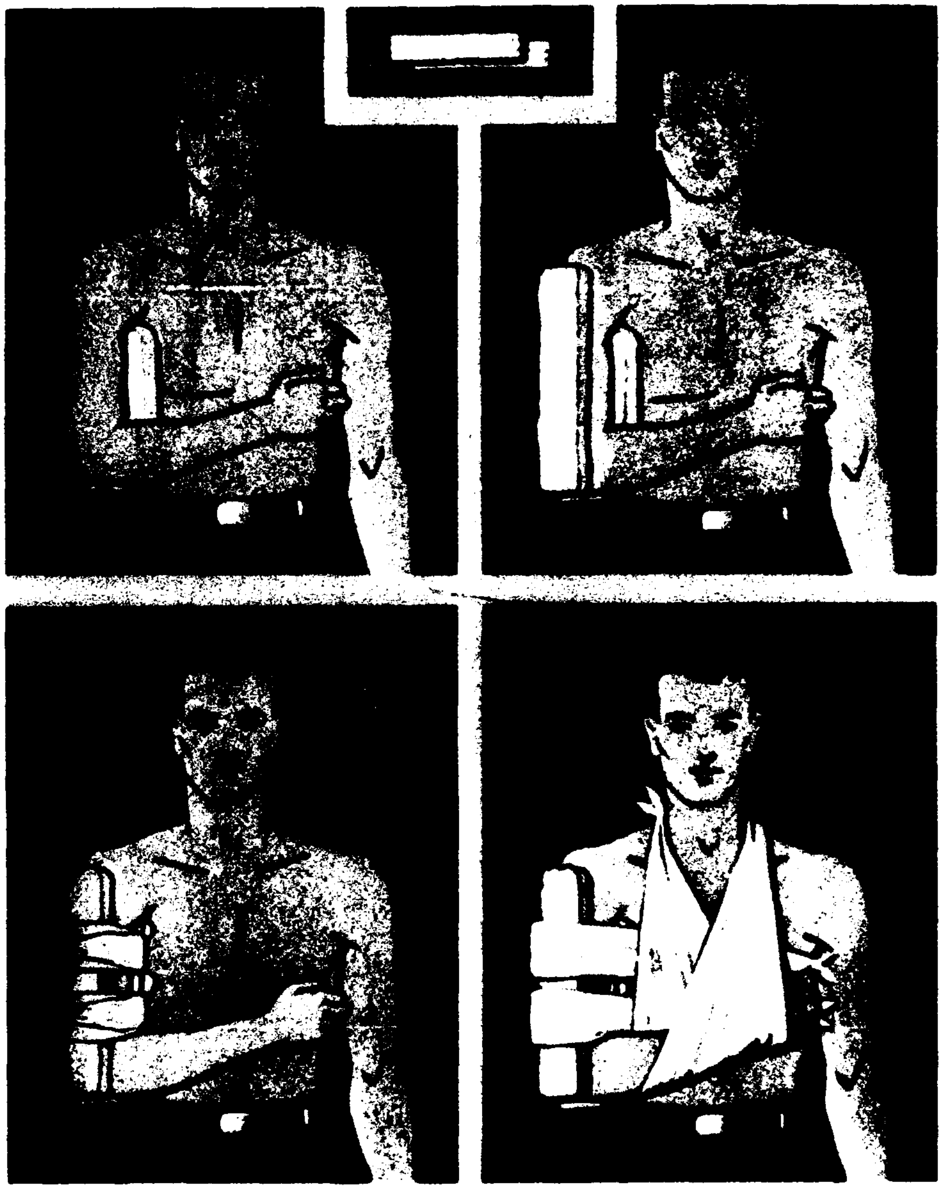


FIGURE 98.—Technique of application of board splint for fracture of humerus (FM 8–50, 1944). A. Pieces of board used for splints. Padding is not shown, but all splints were padded. B. Pad in armpit, to protect blood vessels and nerves from undue pressure. Padded board placed between arm and chest wall. C. Other padded board placed on opposite side of arm. D. Padded boards secured in position with triangular bandages folded as cravats, as shown, or with roller bandages. E. Splinting completed. Forearm in sling at wrist.

Humerus: A wrist sling for fractures of the surgical neck. For fractures of the shaft, a pad between the chest and humerus, with a double sling or Velpeau's type of bandage as in dislocations of the shoulder, supplemented, when practical, by a well-padded external splint.

Elbow: A ladder splint, or a posterior right-angle splint, or a molded plaster splint extending from the shoulder to the metacarpus. Any of these methods was supplemented by a wrist sling.

Forearm: Anterior and posterior molded plaster splints, or well-padded board splints, or a sugar-tongs splint. A sling extending from the elbow to the finger tips was always used.

Wrist: Anterior and posterior board splints or molded plaster splints.

Carpus and metacarpus: Unpadded skin-fitting molded plaster splints.

Phalanges: A roller bandage or molded plaster applied beneath the fingers.

Femur: Skin or skeletal traction for fractures of the neck or intertrochanteric fractures, or an army traction splint, with the leg in internal rotation, this being the only position that holds the fragments of such fractures in position. For fractures of the shaft, skin or skeletal traction in an army traction splint.

Knee: Skin or skeletal traction, or army traction splint, with the knee flexed 20–30 degrees and with a long pad under the flexor surfaces.

Tibia and fibula: A ladder splint, or a plaster splint, or circular plaster, or skeletal traction.

Ankle: A ladder splint or molded plaster.

Os calcis: A ladder splint, or plaster with compression bandage.

Metatarsus: Molded plaster.

Spine: For the dorsal and lumbar spine, transportation in hyperextension, with a folded blanket beneath the kyphos, or a plaster jacket, always bivalved. For the cervical spine, a voluminous cotton collar, small pillow, or gauze roll tight around the neck, supporting the occiput and chin.

Pelvis: A bilateral plaster spica.

Splinting and transportation of patients with compound fractures, it was emphasized, must be carried out with immobilizing apparatus that would prevent further injury of the soft tissues, maintain the position of the bony fragments, and permit dressing the wound as necessary. Prevention and control of shock were paramount at this time. Prevention of infection was of secondary importance. It was recommended (this was 1943) that crystalline sulfanilamide be sprinkled into the wound, supplementary to systemic sulfonamide therapy.

Recommended methods of splinting for compound fractures were as follows:

Humerus: A plaster-of-paris spica, or a molded plaster splint, or a wire splint.

Elbow: Molded anterior and posterior plaster splints, or a ladder splint applied posteriorly, with the wrist in a sling.

Forearm: Molded plaster sugar-tong splints, or wooden splints wider than the forearm, with a triangular sling supporting the entire forearm.

Femur: An army leg splint with traction strap, or skin traction (if the location of the wound permitted it), or skeletal traction, or a plaster spica extending from above the lower ribs to the toes.

Knee: An army leg splint, with the knee in about 15 degrees of flexion.

Tibia and fibula: A molded plaster splint with traction strap, or skin or skeletal traction, depending upon the location and condition of the wound.

Ankle and os calcis: A plaster splint, or a ladder splint, or a compression bandage over a voluminous dressing.

Foot: Molded plaster or a compression bandage with a voluminous dressing.

BANDAGES

Section IV of FM 8–50, 1940 (*3*), described in detail a wide variety of bandages. The manual concluded with a description of various kinds of dressings, especially the standard Army (Carlisle) first aid dressing.

In the 1944 revision of FM 8–50 (*4*), the section on bandaging, which appeared before and not after splints as in the 1940 version, was considerably expanded. A wider variety of bandages was included than in the earlier manual, and the descriptions were given in more detail.

BRACES

Lower Extremity

The most important braces standardized for the lower extremity during World War II included:

1. The non-weight-bearing ischial caliper, which was constructed on the principle that a patient could be ambulatory, with great profit to himself, without actually putting any weight on the injured limb. It was the standard brace for fractures of the femur after union had progressed with immobilization to such an extent that walking would not only aid in the rehabilitation of the muscles and the function of the limb but would also hasten bony union by improvement of the circulation. The brace must be removed several times daily, for knee exercises. The Surgeon General insisted that no knee lock be used on calipers, on the ground that the average soldier could not be depended upon to slip it into place when he stood up, and he would, therefore, risk a fall.

Each brace was made individually, to measure. The brace had to rest on the tuberosity of the ischium, to take the entire weight of the injured extremity plus half the body weight from the pelvis up. The distal end of the caliper was inserted into the tunnel in the heel of the shoe prepared for its reception by cylinder or clamp. To test the efficiency of the caliper, the patient stood upright, with his body weight distributed equally on each extremity. While the examiner placed his finger inside the shoe, under the heel, on the injured side, the patient bore his full weight on that side. If the caliper was fitted correctly, there was no sense of weight on the finger.

2. The bucket brace, which was similar to the ischial non-weight-bearing caliper but incorporated a leather cuff extending from about 2 inches above the knee upward for a distance of 8–10 inches. This was an

extremely useful brace in weak unions, or even in nonunions. While the patient was awaiting surgery, it permitted him to be ambulatory without weight-bearing and thus increased circulation and muscle reconditioning.

3. The long-leg caliper used for knee injuries, and useful whether ligaments or bones were involved. It was made with a long cuff of leather extending above the knee, a similar cuff below the knee, a hinge opposite the ankle joint, and a clasp on the heel of the shoe. It was sometimes made without an ankle joint and placed in a tunnel in the heel of the shoe.

4. The leg caliper brace, which was employed for fractures of the tibia and fibula with good bony union or on the way to good union. When bone grafts had been secured from the tibia (p. 357), this type of brace was worn for 6 or 8 weeks, to prevent fracture of the donor bone. The brace was inserted into the heel and extended to the tuberosity of the tibia; a long leather cuff extended from the ankle to the knee.

5. The drop foot brace, designed to keep the foot in dorsiflexion and useful in nerve as well as orthopedic injuries. It was made in a variety of patterns. One type, which was very light, consisted of a coil or spring inserted into the heel of the shoe; it extended to just below the knee, was secured by leather cuffs, and was reinforced by a metal calf strip. Another type was made of steel, with stop joints at the ankle, and still another consisted of steel uprights with a doorspring device to permit dorsiflexion of the foot by contraction of the spring.

The chief of each orthopedic section decided what type of brace he wished used on his service.

Upper Extremity

For shoulder injuries, airplane (abduction) supports were made to measure in hospital braceshops. For elbow injuries, braces were made with cuffs of leather above and below the joint; the below-elbow cuff incorporated two aluminum or steel bars on the lateral and medial surfaces of the forearm, and there was a hinge at the elbow. These braces were highly efficient in severe elbow injuries.

Various modifications of braces for the wrist were used chiefly in associated injuries of the median, ulnar, and radial nerves, especially in hospitals serving as neurosurgical centers.

Spine

Injuries of the neck were managed in an extension collar, which was designed to support or extend the cervical vertebrae. The collar was adjustable both anteriorly and posteriorly. It fitted the shoulders, and anterior and posterior extension bars connected by straps supported the cuff for the occiput and chin. A brace of this type accomplished both extension and

support and also prevented flexion of the vertebrae and rotation of the head.

The Kirk back brace was used in injuries of the thoracic, lumbar, and lumbosacral areas. Rigid steel or aluminum bars that extended up the back to the shoulder on each side were attached to two pelvic bars about 6 inches apart that extended completely around the back to the anterior spine of the pelvis on each side. The brace was secured over the shoulders, under the arms, across the abdomen, and across the pelvis by leather supports and a belt.

The Kirk brace was generally considered superior to the Taylor brace; once its straps were adjusted, the patient could not control their opening and closing and thus defeat the purpose for which it was worn. Some orthopedic surgeons preferred a brace consisting of a cage of spring steel or aluminum, with a chair back support, connected to bars paralleling the sternum and extending from the sternal notch to the symphysis pubis.

Any type of back brace could be extended up to the occiput and used with a chin support to immobilize lower cervical or upper dorsal fractures.

Web belts or canvas sacroiliac supports proved efficient for the lower back syndrome (p. 825). A pelvic cage made of aluminum or light steel was also useful. A brace of this type, however, was efficient only if it incorporated the entire pelvis and extended well up on the chest, so that the lumbosacral joint was adequately immobilized.

SPECIAL PRECAUTIONS IN SPLINTING THE HANDS AND FEET

Hand.—Although the management of hand injuries is not covered in this volume, since it is covered in detail in the volume on hand surgery in this historical series (*9*), one special precaution in splinting the hand in other injuries of the upper extremity must be emphasized: Mobility of the hand and fingers must be maintained in injuries of the long bones of the upper extremities for which immobilization is necessary (*10*). Often, however, the surgeon who warned his patient to move his hand and fingers made it practically impossible, by improper application of the cast, for him to carry out instructions. Failure to mold the cast adequately and to trim it to conform to the transverse palmar arch was often compounded by unnecessary splinting of the fingers in extension. As Koch and Mason (*11*) pointed out, the line of metacarpal phalangeal joints is not transverse to the long axis of the hand. It is convex dorsally, and it slopes proximally toward the ulnar aspect. If this anatomic fact was overlooked, and if the fifth finger was fixed in hyperextension at the metacarpophalangeal joint, particularly in gunshot wounds of the forearm and wrist, a claw deformity was almost inevitable.

Another error was to immobilize the thumb in hyperextension by placing a wide plaster wedge between it and the index finger. In addition,

the plaster was often trimmed back insufficiently or was molded over the thenar eminence. A residual extension deformity, therefore, resulted in the thumb because of capsular fibrosis in the carpometacarpal joint associated with a compensatory flexion contracture at the interphalangeal joint. Similar inadequate molding limited free motion of the thumb, causing atrophy by both pressure and disuse and thus impairing the most vital function of the thumb; that is, opposition.

If the fingers were immobilized for any length of time in extension, stiffening invariably occurred at the metacarpal phalangeal joints, along with degenerative changes in the terminal phalangeal joints, especially in patients over 30 years of age.

These errors could all have been avoided if the position of function for the hand had always been borne in mind. As Sir Robert Jones described it, it is the position the hand assumes when it holds a large tumbler (*12*). In this position, all the muscles of the hand are relaxed. A satisfactory cast for the hand in an upper extremity injury maintains this position (fig. 99) and, at the same time, extends the wrist to about 30 degrees. The palmar arch is supported by molding the plaster into the hollow of the hand and then trimming it back to a line that coincides with the distal and proximal creases of the palm, thus allowing free and complete lumbrical muscle contraction and metacarpal phalangeal joint motion.

Certain other points had to be borne in mind in this connection. In the interspace between the thumb and the metacarpal phalangeal joint of the index finger, the width of the plaster should be kept to a structurally stable minimum to permit easy approximation of the tip of the thumb to the tip of the index finger. Also, the palmar surface of the thumb should be freed back to the vertical palmar crease to allow for opposition of the thumb toward the tip of the fifth finger. On the dorsum of the hand, the cast should be trimmed back to free the knuckles.

A hand put up in this fashion was very unlikely to suffer any loss of function.

Foot.—The necessity for prolonged immobilization in severe compound fractures and osteomyelitis of bones of the lower extremity had to be balanced by extreme care in trimming the cast and molding it to the foot (*10*). It was not enough merely to apply the cast accurately to the sole. The longitudinal and metatarsal arches also had to be properly fitted. Ending the cast at the metatarsal heads, so that the toes were left unsupported and exposed to the effects of gravity and the pressure of bedclothes, could lead to clawing of the toes (*13*). Impaired function of the extensor tendons was sometimes observed when an attempt had been made to improve the position of the ankle joint after the plaster had begun to set. An isolated clawing deformity of the great toe, in one instance, was caused by traction on the plaster toe piece exerted for this purpose. Continued pressure over the tendons just distal to the ankle joint, even if slight, could also initiate a clawing process.

FIGURE 99.—Correct application of plaster cast to hand. (Top) Volar view. Note that distal edge of cast is cut back to free distal palmar crease and that thumb is freed to vertical palmar crease. (Bottom) Lateral view of hand in cast in position of function. Note that knuckles are free. Note also optimum width of plaster between interspace of thumb and metacarpal phalangeal joint of index finger. (Pruce, A. M.: Arch. Phys. Med. 27: 30–32, January 1946.)

A satisfactory plaster cast for the foot (fig. 100) had to meet certain specifications: It must preserve the arches and prevent clawing of the toes. The plaster platform had to be molded moderately into both longitudinal and transverse arches. The plaster toe piece had to be carried in a straight

FIGURE 100.—Correct application of plaster cast to foot: Cross section of cast, showing plaster toe piece applied smoothly under interphalangeal joint of great toe (a); dorsal edge of plaster trimmed back to free metatarsal phalangeal joint of great toe (b). (Pruce, A. M.: Arch. Phys. Med. 27: 30–32, January 1946.)

plane beyond the tips of the toes, to support them in a neutral position and prevent pressure from the bedclothes. The soft plaster had to be flattened carefully underneath the toes to combat its tendency to wedge under the interphalangeal joints. Finally, the dorsal edge of the cast must be trimmed back to free the metatarsal phalangeal joint of the great toe and the other toes, to permit full dorsal flexion.

SPECIAL DEVICES, MODIFICATIONS, AND IMPROVISATIONS

Plastics and Synthetics

Items made of plastics and synthetics did not come into general use during the war, and most of those proposed were frankly discouraged for various reasons.

At the 24 February 1942 meeting of the Subcommittee on Orthopedic Surgery, Committee on Surgery, National Research Council, a project proposed for the study of plastics for splints was rejected (*14*).

At the 2 June 1942 meeting of the subcommittee, Dr. Roger Anderson demonstrated material made of cellulose acetate or ethyl cellulose and pre-

pared in ribbons 100 inches long, which could be molded to the part to be splinted and was firm within 10–15 minutes after a special solution had been applied to it. This material had the advantages of being transparent and translucent, but the subcommittee was not impressed sufficiently by it to recommend that it be acquired for Army and Navy use (*15*).

At Brooke General Hospital, Fort Sam Houston, San Antonio, Tex., Lt. Col. Milton S. Thompson, MC, and Capt. Rex. J. Howard, MC, with the assistance of the chief orthopedic mechanic, Arthur D. Salmon, constructed braces of Celastic, a synthetic material manufactured by E. I. du Pont De Nemours & Co. The basic splint, made over a plastic mold, consisted of horsehide coated with cellulose cement (made by the Pennsylvania Sole Cement Processing Co.) and covered with Celastic, which, in turn, was coated with cellulose cement and covered with another piece of horsehide. This splint was incorporated easily into a brace and could be used for both upper and lower extremities to provide the rigidity necessary when early ambulation or other movement was desirable. Celastic was also suggested for shoulder caps after shoulder disarticulations, for inner soles in partial amputations of the foot, for night splints, and for a number of other orthopedic purposes. It was light, strong, and easily molded, and was, therefore, well suited for snug-fitting splints of the extremities. Its use was abandoned after the war, with the development of better materials.

At the Camp Swift Regional Hospital, Capt. Garth H. Harley, MC, and Maj. Louis W. Breck, MC, used cellophane, after the technique suggested by McKeever, (1) to prevent fusion of raw surfaces by fibrous tissue in the repair of a lacerated tendon, (2) in a tendon operation on the elbow, and (3) in an excision of a synostosis between the radius and ulna after open reduction and plating of simple fractures. Because they had no cellophane, they used the wrappings of cigarette packages, which they sterilized by boiling. Since this material is inert in tissues, it did not have to be removed, and results in all three operations were good. The method never came into general use, however, and did not survive the war.

Roger Anderson Equipment

At the 2 June 1942 meeting of the subcommittee (*15*), Dr. Anderson was permitted to demonstrate a small unit which had sufficient material to reduce 25 shaft fractures by the half-pin or transfixion pin technique. Designed for frontline use, it consisted of a small stainless steel box, similar to a fisherman's kit, which contained large quantities of pins, bars, nuts, and other items used in external fixation. The box could be sterilized as a unit. The subcommittee, at first glance, was enthusiastic over this kit and considered recommending it for standardization (*16*). In further discussion, however, it was brought out that too few orthopedic surgeons were competent in the use of the Roger Anderson technique to make it safe to

put such equipment into their hands, and the motion to recommend it was—most fortunately—not carried.

Modifications and Improvisations

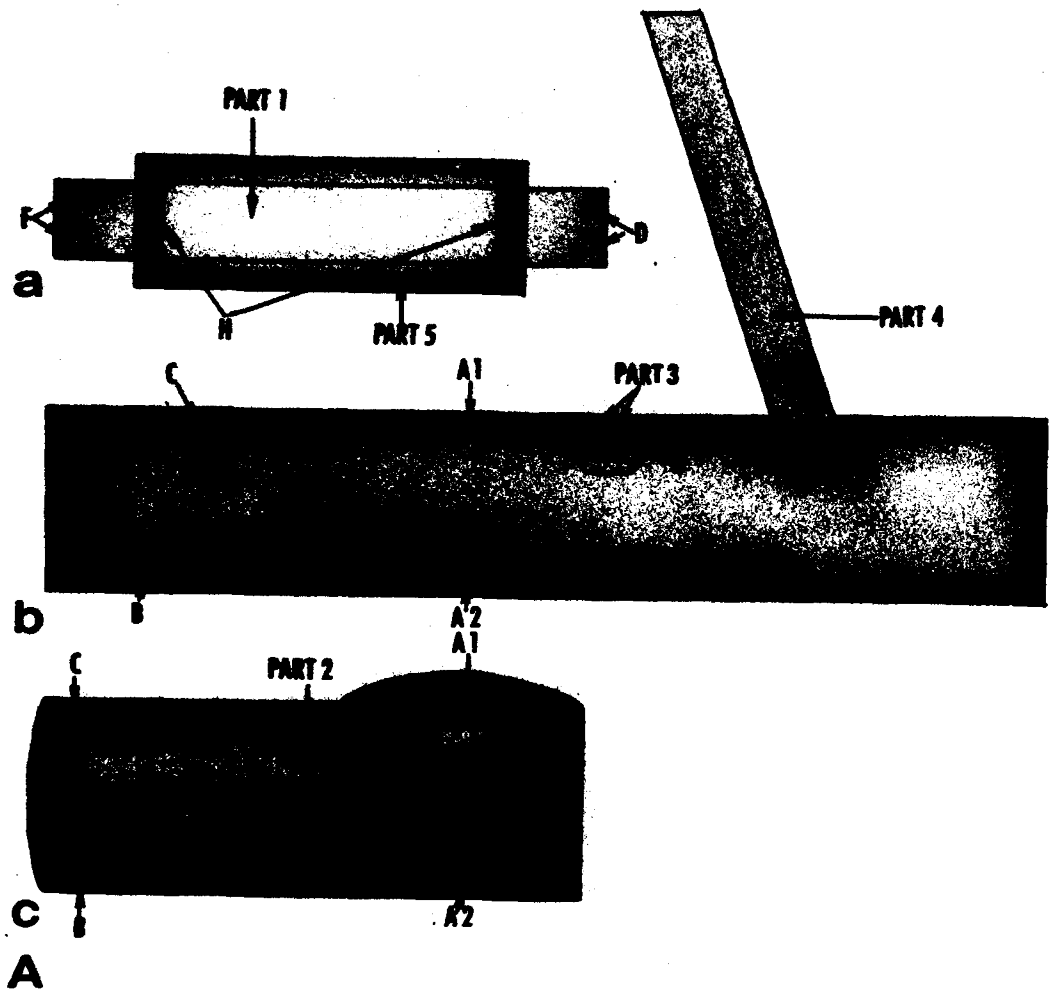
Space does not permit the description of all, or indeed even of many, of the modifications of existing braces and splints or of the new items and the improvisations devised during World War II. Some of them were ingenious and novel. Some of them were obviously useless, for one reason or another, and had no trial beyond their authors' own areas.

Acromioclavicular splint.—The two splints officially recommended for immobilization of the injured acromioclavicular joint both had certain disadvantages. One, made of adhesive tape, almost invariably slipped, and reapplication was necessary. The other, of plaster, was heavy, bulky, and uncomfortable; discouraged early ambulation; was an impediment during transportation; and, most important, did not maintain the proper pressure on the joint.

An effective substitute was devised at the hospital at Hobbs Army Air Field, Hobbs, N. Mex., by Capt. Elvin L. Fitzsimmons, MC, with the assistance of Cpl. Sylvester V. Prokash. The idea of constructing such splints of muslin or canvas was not new, but the proposed modifications were.

The splint (fig. 101) was made of heavy muslin, with rubber tubing used to maintain pressure over the acromioclavicular joint. Improvements over existing muslin splints included the use of webbing to prevent tearing of the sleeve at points of stress; the double stitching of the sleeve to the belt; closure of the sleeve at the elbow, to prevent posterior movement of the arm; and passage of the shoulder strap through the felt pad to prevent its slipping. This splint was lighter than the plaster splint and, by increasing the patient's comfort, it contributed to earlier ambulation. Its light weight made it ideal for transportation. It could be used during conservative treatment as well as after surgery, and could also be used with a plaster forearm splint or a hand splint. It was easily applied and adjusted. The rubber tubing on each side provided a continuous dynamic force which was anatomically correct.

Traction cradle.—The Böhler-Braun frame proved extremely useful in the treatment, by skeletal traction, of fractures of the femur or tibia, but it was not always available. In the European theater, an improved type of traction cradle based on this frame gave excellent service (*17*). At Camp Maxey, Tex., Capt. (later Maj.) Samuel H. Nickerson, MC, devised a wooden prototype of the Böhler-Braun frame, which could be constructed easily by any competent carpenter (figs. 102 and 103) (*18*). There was sufficient room for both the patient and the splint on a hospital litter with skeletal traction still functioning. In two instances at Camp Maxey, open reduction was performed without any disturbance of traction. Roentgenograms could also be taken without disturbing the splint. There were no ropes and pulleys to be dismantled, as in the conventional overhead suspension, so movement to another bed, another ward, or even another hospital



SEW DOTTED LINES A1 TO A2 INSIDE OF SLEEVE TO DOTTED LINES A1 TO A2 OF BELT. SEW BOTTOM EDGE LINES OF SLEEVE, A2 TO B, TO BOTTOM EDGE LINES A2 TO B OF BELT. SEW OR PIN TOP EDGE C OF SLEEVE TO C OF BELT.

USE 2" WIDTH SPLINT WEBBING FOR PARTS 1, 2, 3 & 4. USE FELT PADDING FOR PART 5. *INTERLACE 5/16" DIAMETER* RUBBER TUBING THROUGH HOLES D TO E AND F TO G. CUT FELT THROUGH ON LINES H AND INSERT SHOULDER STRAP. SEW PARTS 3 AND 4 TO BELT AND PART 2 TO SLEEVE AS INDICATED BY DOTTED LINES ON DIAGRAM. WHEN SEWING SLEEVE & PARTS 2, 3 AND 4 TO BELT USE DOUBLE STITCH. . . .

FIGURE 101.—*See opposite page for legend.*

FIGURE 101.—Modified splint for acromioclavicular injuries. A. Components of splint: Shoulder strap (a), sleeve (b), and belt (c). B. Anterior view of splint on patient who required surgical correction of injured coracoclavicular ligament and who also had a Colles' *fracture*. C. Posterior view.

was possible with the apparatus in place. These advantages were particularly important in the event of fire or other emergency.

Braces for foot drop.—The two standardized braces used to prevent foot drop in World War II were both open to objections. The standard metal brace with drop lock ankle was cumbersome and had no spring. The wire brace had a spring at the ankle, but the wire bent readily and often broke.

A modification of the latter brace, devised by Jack R. Pava, the orthopedic mechanic at Hoff General Hospital, Santa Barbara, Calif., eliminated this objection by placing the upright in front of the coil rather than behind it, so that the weight of the foot compressed the spring instead of opening it and thus increased its efficiency (*19*). Replacement of the spring for breakage or undue relaxation was seldom necessary. The use of a half metal band around the calf of the leg posteriorly, between the uprights, added to the wearer's comfort and did away with the twisting of the brace around the calf, which was always a possibility when a flexible strap and buckle were used around the anterior part of the leg. With the half band in place, the steel uprights of the brace remained parallel and lateral to the leg, and provided even tension for the foot in neutral position.

The modified splint could be worn with different changes of shoes. All that was necessary to adjust it to a new pair was to drill a hole one-fourth of an inch in diameter through the heel of the shoe and insert a metal

FIGURE 102.—Maxey (Camp Maxey) splint in use on fracture of right femur.

tube into the hole. Multiple braces for different shoes, which were necessary when the foot drop was bilateral, were therefore unnecessary. With this brace, there was also no need for nailing or riveting the crosspiece to the sole of the shoe.

Another effective splint for the correction of foot drop consisted of molded plaster foot and calf pieces, lined with felt and jointed by a wire-ladder splint that served as a hinge (fig. 104). The ladder was so bent as to clear the heel and avoid pressure on it. Elastic cords on each side extended from the proximal end of the calf pieces to the distal ends of the foot pieces. The splint was held in place on the extremity by three straps and buckles which were incorporated in the plaster pieces.

The arrangement of the elastic cords depended upon the purpose for which the splint was intended. If it was to prevent equinus, they were fastened with just enough tension to hold the foot in neutral position. More tension was used if equinus had already developed. Inversion and eversion were controlled by increasing the pull on either the lateral or the medial cord. If equinovarus was marked, the lateral cord was placed obliquely, so that it extended from the region of the little toe to the medial aspect of the calf piece. If simple varus deformity existed without equinus, the lateral cord extended from the region of the calcaneocuboid joint to the medial aspect of the calf.

This splint had a number of advantages: It was readily removed and replaced. Constant elastic pressure kept it in contact with the foot, and the

FIGURE 103.—Bilateral fractures of femur treated by skeletal traction and Maxey (Camp Maxey) splint. Fracture on left (in upper third of femur) is treated by supracondylar skeletal traction. Fracture on right (oblique and supracondylar) is treated by open operation during continuing skeletal traction through the tibia. A. Patient in bilateral traction and Maxey splint. B. Anteroposterior roentgenogram showing fracture of femur on right before operation. C. Anteroposterior roentgenogram of same after application of traction. D. Lateral roentgenogram of same.

flat surface of the wire ladder helped prevent rotation of the limb. The fibrosis so common when rigid splinting was employed did not develop with it. There was no pressure over the Achilles tendon or its insertion. The splint not only exerted a corrective elastic pull but also permitted the use

FIGURE 104.—Elastic splint for drop foot. (Top) Interior of splint. (Bottom) Splint applied to foot after delayed primary closure of ankle wound.

of exercises to maintain the strength of the plantar flexors of the ankle, which had to contract against the resistance of the elastic cords. If a tendency toward external rotation at the hip became evident, a section of basswood splint or a small piece of wood was attached to the splint, to increase the width of the hinge action.

Walking calipers.—Lt. Col. J. Sims Norman, MC, at Camp Pickett, Va., used a walking caliper with a slot in the bar on each side of the knee, an

arrangement that made the caliper practical for a patient with a slightly flexed knee. As extension capability increased, the brace could be straightened and adjusted by means of a screw in the slot.

Another useful walking caliper was devised by Maj. George S. Phalen, MC, at O'Reilly General Hospital, Springfield, Mo., for compound fractures involving the acetabulum and the head and neck of the femur (*20*). These fractures were relatively frequent and many of them were complicated by osteomyelitis and suppurative arthritis. Some wounds drained for months, in spite of adequate surgery and antibiotic therapy. Cultures usually revealed penicillin-resistant organisms of the *Proteus* group, often in pure culture.

When the hip joint was involved in such a suppurative process, it had to be immobilized to control pain and prevent deformity. These objectives could be efficiently accomplished by a hip spica cast, but the encasement of the lower extremity in such a cast for several months was certain to result in varying degrees of fibrous ankylosis of the knee and ankle, even though these joints had not been involved in the original trauma. Attempts at mobilization after the removal of the cast were time consuming, unduly prolonged the period of disability, and were not always successful.

Caliper braces with pelvic bands or body corsets used to immobilize the hip were expensive to construct, uncomfortable when they were worn day and night, as they had to be, and did not readily permit dressing or irrigation of wounds about the hip. Major Phalen overcame these difficulties by the use of a single short hip spica cast into which was incorporated a long-leg caliper attachment (fig. 105). This attachment was fitted with hinges at the knee, with a stop to prevent extension beyond 180 degrees, and with drop lock keepers to hold the joint in complete extension when the patient was ambulatory. The caliper attachment was fitted into the forward portion of the heel of the shoe or just in front of it. The shoe was easily removed, but if it was not worn at night, some other provision, such as binding the lower leg snugly against the caliper uprights with elastic bandages, had to be made to prevent external rotation of the extremity. Any flexion deformity of the knee had to be corrected before the brace was applied.

This brace served as a non-weight-bearing splint by adjustment of the length of the caliper attachment. The weight thrust upon the involved lower extremity was transmitted by the caliper uprights into the short spica cast, which encased the entire pelvis. The brace thus served the function of the ischial weight-bearing Thomas splint, with the additional advantage that it immobilized the hip joint. Patients found it considerably more comfortable than the Thomas splint.

Apparatus for rotatory motions of forearm.—Much more emphasis was placed in rehabilitation upon extension and flexion of the elbow than upon rotatory movements (pronation and supination) of the forearm in injuries involving the radius and ulna. One reason seemed to be that few physical therapy departments had proper devices for practice of these

FIGURE 105.—Walking (cast-brace) caliper in use. This patient sustained a compound fracture through the acetabulum and femoral head when he was wounded in action by a machinegun bullet. Subsequent chronic suppurative osteomyelitis required prolonged immobilization of the hip joint. A. Front view, with weight on both feet. B. Front view, with weight on left leg. Shoe has been removed from caliper attachment. C. Side view, same.

motions. The simple apparatus devised by Capt. Joshua Ehrlich, MC, was intended to correct this deficiency. It consisted of:

1. A plank that slid vertically between two pieces of wood and that could be adjusted according to the height of the individual patient.
2. Two wooden wheels, of different diameters, fastened to the plank by a bolt through their centers. The larger, thinner wheel was graded from 0 degree to 180 degrees on each side of a vertical line that crossed its center. The smaller, thicker wheel was grooved and was provided with a handle. A weighted cord was attached to this wheel in such a way that when the handle was turned, the cord entered the groove.

The patient operated the device with his intact arm strapped to his body, to eliminate any movement of the shoulder on that side. He grasped the handle of the device with the affected hand, with his elbow bent at 90 degrees, and endeavored to turn it to make the cord enter the groove. His achievement was measured in degrees.

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CHAPTER XII

Internal Fixation of Fractures

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GENERAL CONSIDERATIONS

Little time need be spent on a discussion of internal fixation in noncombat, civilian-type fractures encountered in the Zone of Interior. It was performed with the same indications as in civilian practice, and, when limited to those indications and when performed by experienced orthopedic surgeons, it gave generally good results. At the Army Air Forces conferences in October 1943 (*1*), for instance, Lt. Col. (later Col.) Alfred R. Shands, Jr., MC, mentioned 39 civilian intertrochanteric fractures of the femur treated by this technique, and recommended it for such injuries on the ground that the anatomic and functional results were better than with nonsurgical methods, and less time was lost from duty.

On the other hand, internal fixation was not always performed within the proper indications. Both civilian and military consultants in orthopedic surgery frequently commented on the tendency in Zone of Interior hospitals to perform it (as well as other radical surgery) in circumstances in which more conservative measures could have been used with less risk.

To understand the status of casualties with battle-incurred compound fractures received in Zone of Interior hospitals from overseas after internal fixation, it is necessary to outline briefly the policies and practices used in those theaters with respect to this technique.

OVERSEAS POLICIES AND PRACTICES

Mediterranean Theater

Official policies.—Internal fixation was mentioned in three directives issued in the North African and Mediterranean theaters during World War II:

1. In Circular Letter No. 13, Office of the Surgeon, North African Theater of Operations, dated 15 May 1943 (*2*), the use of bone plates or screws was not recommended forward of evacuation hospitals.

2. In Circular Letter No. 48, Office of the Surgeon, North African Theater of Operations, dated 18 November 1943 (*3*), it was pointed out that delayed open reduction and internal fixation of compound fractures, with or without delayed secondary

(that is, delayed primary) suture of the wound was still under trial with respect to indications, risks, and complications. Its use was restricted to special groups authorized to carry out special studies, to be described shortly.

3. Circular Letter No. 8, Office of the Surgeon, Mediterranean Theater of Operations, dated 10 March 1945 (*4*), was far more specific. The substance of this letter, which was repeated almost verbatim in War Department Technical Bulletin (TB MED) 147, also issued in March 1945 (*5*), was as follows:

a. Internal fixation has no place in transportation splinting after initial wound surgery in a forward hospital unless it is necessary to preserve the vascular integrity of a damaged extremity.

b. This technique is not commonly feasible in battle injuries because of their excessive comminution. It is also undesirable because it requires periosteal stripping and introduces surgical trauma into the wound.

c. It is strongly recommended that its use be limited to orthopedic specialists with wide experience in its techniques and risks.

d. Both Circular Letter No. 8 and TB MED 147 ended with the same statement, "Reduction of the fracture is the goal of reparative surgery—not the use of internal fixation."

Development of policies.—Internal fixation was given an extensive clinical trial in the Mediterranean (formerly North African) theater (*6*): [1]

It was never performed as a primary procedure; and during the first 16 months of active operations in the theater, it was seldom performed at all, even when it was believed to be indicated, because of fear that surgical intervention would incite systemic infection, or at least a severe wound infection, with prolonged osteomyelitis. During this period, it seemed wiser to accept inadequate reduction rather than take these risks. Investigation of small series of operations at two hospitals and of sporadic cases throughout the theater did not produce evidence sufficient to warrant recommendation or approval of this technique.

The special studies authorized in Circular Letter No. 48 (*3*), published in November 1943, were delayed for further experience in wound management and until adequate supplies of penicillin should become available. These studies began in March 1944, and the immediate results in small series of fractures at three general hospitals seemed to justify internal fixation on specific indications after other criteria of wound management had been met. It was accomplished by plating, multiple screws, or wire sutures. This technique was suitable for only a small number of fractures because of the frequency of extensive comminution, which was a definite contraindication to it.

After internal fixation had been extended to all general hospitals in the Mediterranean theater as part of the program of reparative surgery, the results were carefully analyzed and were found satisfactory in the majority of cases in the sense that the incidence of wound infection had apparently not been increased, drainage had not been unduly prolonged, fracture reduction was improved, and final scar formation was expected to be less. In

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[1] It should be remembered that a large number—perhaps the majority—of orthopedic surgeons in the Mediterranean theater were on the staffs of affiliated units and were, therefore, well trained and experienced.

spite of repeated warnings, however, some orthopedic surgeons continued to use internal fixation in fractures of the tibia and thus created major problems for themselves and others.

European Theater

Official policies.—Internal fixation was a policy never encouraged, but rather actively discouraged, in the European theater in World War II (*7*). It was, of course, not mentioned in the section on surgical emergencies in the "Manual of Therapy, European Theater of Operations," issued on 5 May 1944, just before D-day (*8*). In the section on definitive treatment, reduction of the fracture was described as desirable if the reduction could be maintained by splinting, but as "*not of prime importance. The control of infection is of major concern* at this time." The instructions were mandatory: "*Do not attempt internal fixation* by any foreign material." No method of fracture reduction was to be employed which might cause infection to be disseminated in the fracture fragments.

Circular Letter No. 131, Office of the Chief Surgeon, dated 8 November 1944 (*9*), directed the treatment by traction of fractures of the femur, tibia, fibula, and humerus in every instance in which "beneficial" results could be expected within a reasonable time. Internal fixation was not mentioned.

Circular Letter No. 23, Office of the Chief Surgeon, dated 17 March 1945 (*10*), was specific about internal fixation. Recent reports from the Surgeon General's Office on the condition of battle casualties thus treated had not been favorable (p. 383). The consensus by qualified chiefs of orthopedic services and surgical services in 19 named general hospitals in the Zone of Interior, concurred in by orthopedic consultants, was that metallic internal fixation of compound fractures resulted in infection in 25 to 50 percent of all cases (p. 386). The metallic fixing agent had to be removed in all of these infected fractures, and delayed union or nonunion resulted in many instances.

In view of this adverse report, the letter continued, internal fixation of compound fractures was prohibited as a routine procedure in the European theater. It was to be resorted to only after (1) a thorough trial of skeletal traction had failed to secure good reduction and (2) healing of the compounding wound had been accomplished by delayed primary wound closure or skin graft. Every contemplated operation must have the approval of the appropriate orthopedic or surgical consultant. Fractures associated with peripheral nerve injuries were to be treated at specialized hospitals designated for neurosurgical problems.

Development of policies.—In the European theater, which did not begin to receive battle injuries until more than 2 years after it had become operational, open reduction and internal fixation were probably used more often than they should have been before D-day. Even in simple fractures,

it sometimes seemed the only way to secure union with proper alinement. In compound fractures, internal fixation was sometimes a useful technique in carefully selected cases, particularly in fractures of the long bones adjacent to joint surfaces. It was often, however, an extremely formidable procedure, and one completely unsuited for general use.

Internal fixation was used with relative safety early in the operations of the European theater, when general and station hospitals were staffed with qualified orthopedic surgeons experienced in this technique. It became a far less desirable procedure for noncombat injuries even before D-day, when the hospitals arriving from the Zone of Interior were staffed with surgeons less adequately trained in bone and joint surgery. With the great majority of surgeons who were to treat combat injuries both undertrained and inexperienced, disaster would have been inevitable if permission had been given for general use of this method. It was, therefore, prohibited as a primary procedure.

This prohibition was generally observed before D-day, and when internal fixation was used, it was generally with discretion and with good results. The procedure, however, had been permitted routinely in the Mediterranean theater; and when the hospitals in the Seventh U.S. Army, which had originated in that theater, passed under control of the European theater on 20 November 1944, some 3 months after the invasion of southern France, it was some time before information concerning the prohibition of internal fixation was generally disseminated among them.

Pacific Ocean Areas

Official policies.—The complex organization of the various areas in the Pacific and the peculiar and unpropitious circumstances under which medical care was administered make clear why formal general policies concerning internal fixation did not exist there. The first mention of internal fixation in any of the Pacific Ocean Areas was apparently in Technical Memorandum No. 1, Office of the Chief Surgeon, U.S. Army Services of Supply, issued on 5 January 1944 and entitled "Surgical Principles for the Forward Area Units" (*11*). In the directions for fracture management, under the heading of immobilization (paragraph 4d), plating was "deprecated" in any advanced unit because of the risk of infection and of damage in transportation.

The directive issued to all medical officers in the Pacific Ocean Areas dealing with surgery in the combat zone on 27 February 1945, from the Commanding General, Headquarters U.S. Army Forces, Pacific Ocean Areas (*12*), specified that internal fixation with metallic agents was not to be used at initial wound surgery. Good length and alinement could usually be secured by other means, and this technique was to be reserved for rear hospitals, where definitive treatment could be carried out. An addendum

to this letter, dated 6 April 1945, prohibited this technique in the primary treatment of compound fractures of the long bones except in occasional cases, when the fracture was into the joint, to restore joint continuity.

Lt. Col. (later Col.) Harold A. Sofield, MC, who served as Consultant in Orthopedic Surgery in the Central and later in the South Pacific, in a memorandum to the Surgeon, Tenth U.S. Army, on the Okinawa operation, dated 7 June 1945, listed among the orthopedic errors he had observed the "unjustified" use of internal fixation (*13*).

Postwar evaluations.—Dr. (formerly Lt. Col., MC) George O. Eaton, in reply to a query on the subject in April 1966 (*14*), stated that internal fixation was originally used in the Southwest Pacific Area, where he served as Consultant in Orthopedic Surgery, by medical officers trained in the method, but soon was routinely discouraged in all parts of the area because of its risk in the hands of surgeons not fully trained in the technique. Its selective use was permitted, when attempts at closed reduction had failed or when displacement of fragments jeopardized the circulation or the nerve supply of an extremity. In retrospect, Dr. Eaton doubted that it would have been practical to have fixed regulations that would cover all aspects of internal fixation in such a theater as the Southwest Pacific.

A postwar report by Col. William Barclay Parsons, MC, Consultant in Surgery, Southwest Pacific Area (*15*), stated that internal fixation was not approved forward of general hospitals or large, well-staffed station hospitals acting as general hospitals because of the serious risk of infection. Even if wounds healed without infection, Colonel Parsons questioned whether anything had been gained by internal fixation under these circumstances.

In his postwar report on orthopedic surgery in the South Pacific Area, Maj. John H. Aldes, MC, 8th General Hospital, called attention to the ill-considered application and poor results of this technique in the hands of ill-trained surgeons in forward hospitals (*16*). He cited Colonel Sofield's comments to the same effect.

Col. Robert C. Robertson, MC, wrote the final report on orthopedic surgery in all areas of the Pacific, including the Hawaiian Department and covering the period from March 1942 to September 1945 (*17*). His remarks on internal fixation are in substantial agreement with those just cited: Internal fixation was not indicated as a primary procedure. It should be used only after delayed primary wound closure, when closed techniques were unsatisfactory. It had a limited field of usefulness because of comminution of combat-incurred fractures, extensive loss of soft tissue, and the circumstances of warfare and medical care in the Pacific. Metal plates should be used only in transverse fractures, which do not lend themselves to the use of screws. Internal fixation was best reserved for compound fractures involving the joint or for those in which continuity of the shaft could not otherwise be preserved.

When penicillin became available, some orthopedic surgeons were inclined to widen the indications, but the general feeling in the Pacific Areas

was that this method should be employed only when the fracture was of such a type that the recognized risk of infection was offset by the anticipated improvement in the anatomic and functional results.

When Maj. Gen. Norman T. Kirk, The Surgeon General, visited the Pacific in February 1945, he placed constant emphasis on the use of traction for fractures of the long bones until sufficient bony union had occurred to permit evacuation in plaster.

EVALUATION IN ZONE OF INTERIOR HOSPITALS

The practices and policies just summarized in overseas theaters provided the background for the reception and management of patients in Zone of Interior hospitals after internal fixation overseas. The number of such patients became smaller as the war progressed and as the technique lost much of its popularity in the Mediterranean theater and was prohibited in the European theater.

Shortly after General Kirk became The Surgeon General, in 1943, he prohibited the use of internal fixation entirely. One reason was his strong conviction that any procedure recommended or permitted for general use must be safe not only in the hands of well-trained surgeons but also in the hands of the general run of surgeons. This latter group, as he knew by experience, were attracted to a procedure, learned it incompletely, and performed it with limited effectiveness and safety. The prohibition seemed particularly needed in an operation such as internal fixation, which represented a departure from formal surgical principles. In the military services, the axiom, "Whatever is best for the greatest number is the best for all," should be the policy for treatment.

Orthopedic surgeons in the Zone of Interior tended to be critical of internal fixation, performed overseas. In many simple fractures, this technique seemed to them unnecessary. When the fractures were compounded, the considerable incidence of infection seemed to them too high a price to pay for the results achieved. The immediate results might be good enough to explain the enthusiasm for it of overseas surgeons. They had little opportunity to observe their patients later when delayed infection had developed. The end results, in spite of the restoration of axis alinement and end-to-end approximation of bone fragments, were often "vicious," according to the orthopedic surgeons at Vaughan General Hospital, Hines, Ill. (p. 387).

Other observers in the Zone of Interior were equally emphatic in their condemnation of internal fixation. Lt. Col. Leonard B. Barnard, MC, Woodrow Wilson General Hospital (Staunton, Va.), based his remarks on his observation of 107 fractures of the femur sustained overseas and variously managed by plaster, traction, and internal fixation (*18*). The best results, both anatomically and functionally, were secured by traction. In-

ternal fixation of fractures of the femur, Colonel Barnard thought, "except in rare instances does not give satisfactory end result in military operations." He concluded, "The attempt to achieve anatomical position as is practiced in the carpenter trade should be exchanged for an outlook towards functional end results. As Watson-Jones states, 'Aposition of the fragments is relatively unimportant and maintenance of full length and normal alignment are the only requisites for a good result.' "

PROGRESS SURVEY

Although the results of internal fixation seemed highly satisfactory in the Mediterranean theater, it was realized that investigations in the Zone of Interior would be necessary before valid conclusions could be drawn concerning its worth. The appropriate survey was carried out by the Consultant in Orthopedic Surgery of the Mediterranean theater, Lt. Col. Oscar P. Hampton, Jr., MC, between 16 March and 26 April 1945, in 24 Zone of Interior general hospitals (*6*). It covered 332 fractures managed by internal fixation in 18 general hospitals in the Mediterranean theater between 4 June and 1 November 1944 by 50 orthopedic surgeons. Since 32 records were incomplete, the analysis was limited to 300 fractures in 295 patients.

The results of this investigation are reported in detail, from various aspects, in the volume in this historical series dealing with orthopedic surgery in the Mediterranean theater (*6*).

There were no deaths in the series, and no amputations were necessary. The investigating officer considered the results to be optimum in 226 cases and unfavorable in varying degrees in 53 cases, including 20 operations on the tibia and fibula, 19 on the femur, nine on the humerus, and five on the radius and ulna. In the remaining 21 cases, sufficient time had not elapsed since operation to permit evaluation of results.

The following conclusions were drawn from this survey:

1. Internal fixation, when used on the proper indications and performed by the correct technique, has a limited but definite place in the management of combat-incurred compound fractures of long bones in fixed hospitals overseas. To meet these criteria, it must be performed as an adjuvant measure and within the strict limits of reparative surgery.

2. The chief hazard of this technique is increased sequestration, explained by the periosteal stripping that is part of the technique, particularly when plates are used. Sequestration occurred in 69 of the 168 fractures treated by plating and was sometimes so massive that the resulting bony defect could be compensated for only by bone grafting.

An editorial note attached to this report (by Col. Mather Cleveland, MC, Consultant in Orthopedic Surgery, European theater) stressed the peculiar risk of fixation of combat-incurred fractures of the tibia with

plates and screws: "* * * Unfortunately, these techniques are the easiest to perform. These facts should be brought home to every medical officer. Otherwise, the tibia will continue to serve as a boobytrap for the unwary, incompletely trained surgeon, with the wounded soldier as the victim."

MATERIALS FOR INTERNAL FIXATION OF FRACTURES

The development shortly before and during the war of such noncorrosive materials as stainless steel, Vitallium, and tantalum permitted their use in internal fixation of fractures; and, when this procedure was used with due regard for its limitations, they aided greatly in the accurate reduction and fixation of injuries involving the weight-bearing joints (*19*). There was no doubt, however, that the occurrence of incomplete fixation, infection, nonunion, and other complications, while sometimes attributable to faulty technique, was also often due to the defective design of the devices used for this purpose. This was clearly evident in the broken and bent plates, screws, and other items which at intervals reached the Surgeon General's Office (*20*). The breakage of solid Steinmann's pins was particularly serious when they were incorporated in casts for transportation and was particularly frequent when the pins were jointed in the middle by threads, to facilitate their removal. The fact that osteomyelitis did not always develop in situations that were an invitation to its occurrence seemed to support the rather general opinion that reactions to pinning differ from individual to individual.

Inadequate manufacturing specifications explained most of the defects reported, and repeated revisions were made. Finally, a comprehensive investigation was undertaken, in cooperation with the National Bureau of Standards and the Subcommittee on Bone Plates and Screws of the Committee on Fractures and Other Trauma of the American College of Surgeons, with the objective of preparing comprehensive, definitive specifications for these items. In the meantime, in December 1944, the situation was summarized as follows (*21*):

1. Vanadium had been declared obsolete some time previously; when it was removed from old healed fractures, a considerable reaction was invariably evident. Vitallium was formerly standardized, but depot stocks were now exhausted; hospitals which still possessed fixation devices of this material were urged not to use them in combination with devices containing steel because of the risk of setting up an electrolytic reaction. Tantalum had been used in only a few fractures to date and had not been standardized.

2. Standardized bone plates and screws in use at this time were all of stainless steel.

3. No standard test had yet been devised on which to calculate the required strength of plates of various materials. They should always be tested before use and discarded if they broke or if they could be bent.

4. Breakage of both steel and Vitallium screws could usually be attributed to the use of improper drill sizes, strain on the fracture site, and incomplete fixation as well as to defective material and workmanship in the fixation agents. A number of standardized screws had recently been found to be defective; the defect interfered with their thread-cutting quality, and therefore with their holding properties.

5. Steinmann's pins were made of stainless steel and their cutting points had recently been improved, though they must not be pounded through dense cortical bone, for fear of fracturing the bone as well as damaging the pin. The numerous breakages reported in the pins produced by one manufacturer had now been controlled. Jointed Steinmann's pins had been declared obsolete some time previously. They broke easily, and fragments were sometimes retained in the bone.

6. Flexible wire was provided in four standard sizes. It was available in both steel and tantalum, but only a single kind should be used in a given case. Wire fixation lacked stability and was not recommended for the shafts of long bones. When it was used for this purpose in other bones, care was to be taken that the material used was strong enough to permit early joint motion when that was desirable, as it was, for instance, in fractures of the patella and the olecranon. Several strands of fine wire twisted together were sometimes better than a single strand of heavier wire. Breakage was fairly common because the strength of the wire selected was overestimated.

7. The standard tibial bolt, which had not been entirely satisfactory, would in the future be made of stainless steel with a solid head and with two washers and two nuts. This was a useful item when compression was desired. Its length could be adjusted as necessary.

8. Parham bands were not furnished as a standard item, and their use was not approved; they caused considerable tissue reaction, and their constricting effect caused pain and could result in bony necrosis.

9. All material used for fixation of fractures at this time should be examined carefully before use, for present materials and designs were by no means ideal and new specifications were not yet ready.

COMPOSITE SURVEY IN THE ZONE OF INTERIOR

The investigation mentioned earlier in this chapter (p. 383) of internal fixation in returned orthopedic casualties was limited to operations performed overseas, within 2 days to 2 months after injury of the femur, tibia, humerus, ulna, and radius, either singly or in combination. It was requested that results be stated in terms of union and infection. Union was defined as lack of clinical motion, with roentgenologic evidence of good callus formation. Superficial ulceration was not classified as infection, which was diagnosed by persistent drainage, sinus formation, and roentgenologic evidence of osteomyelitis.

The results reported in the December 1944 survey varied widely but were considered as generally unfavorable:

1. Malunion and nonunion were frequent.
2. Many casualties apparently treated successfully overseas later developed secondary infection and abscess formation. Even simple fractures that had been plated —why this procedure had been used was not always clear—sometimes showed infection 3 or 4 months after operation.
3. Almost without exception, infection required removal of the fixation materials, particularly plates, which meant secondary surgery and frequently prolonged drainage.

4. Orthopedic surgeons in the Sixth Service Command estimated that results in the patients received in the Command hospitals after internal fixation were excellent in 25 percent and extremely poor in 25 percent. A followup of 20 patients received from the European theater indicated that union was not expedited by this technique.

5. At Halloran General Hospital, Staten Island, N.Y., where more than a hundred patients were examined, some results were classified as excellent, some as fair, and some as "terrible," with an intermediate group in which results were classified as neither good nor bad. Good results, however, did not cancel out poor results. If they had, a better selection of cases might have eliminated the poor results. It would have been desirable, the staff concluded, for overseas surgeons to see the end results of their work in Zone of Interior hospitals.

In November 1944, the chief of the Orthopedic Section at this hospital was unwilling to commit himself definitely on the subject of internal fixation beyond saying that if this technique was employed, patients should be selected more carefully. The following month he said that if he were asked to assume the responsibility for sanctioning or discarding this technique, he would act unfavorably and then "rest uneasy because of the conviction that my decision had been reached after an entirely inadequate appraisal."

6. In one group of 15 patients, chiefly from the Mediterranean theater, 11 had excellent results and three had only minor complications. But the remaining patient developed severe, extensive osteomyelitis and suffered an almost disastrous loss of bone substance. With good results in 11 of 15 cases, it was a temptation to become enthusiastic over the possibilities of this technique, but one had only to recollect the "atrocious" results in the case just described—and in many similar cases—to lose his enthusiasm.

Anatomic location of injury.—The December 1944 survey made it clear that the anatomic location of the injury had a decided influence on the outcome of surgery. At Halloran General Hospital, in seven cases in which the tibia was plated, prompt healing occurred in only one. At Deshon General Hospital, Butler, Pa., fixation was satisfactory in nine of 11 operations on the femur, but in only seven of 15 on the tibia.

Timing of operation.—The crux of the discussion about internal fixation was not so much the rationale of the procedure itself as its timing. The most experienced orthopedic surgeons, both overseas and in the Zone of Interior, believed that the correct treatment for compound fractures of the long bones was prompt debridement; delayed primary wound closure, preferably within a few days, certainly within 2 weeks, after debridement; maintenance of undisturbed traction for 7–8 weeks at least; return to the Zone of Interior; and then, if necessary, internal fixation. As a delayed procedure, this was a highly successful operation in properly selected cases. The many adverse comments as to its effectiveness made in the Zone of Interior usually concerned not the quality of surgery but the time sequence.

The general feeling about internal fixation was well expressed by Col. Robert H. Kennedy, Consultant in Surgery, Second Service Command: If early internal fixation succeeded, a great deal of time was saved in the patient's recovery. If it was not successful, more time was lost than would have been lost in the ordinary course of events, complications were likely to be severe, and death was a possibility.

Removal of fixation agents.—In many cases of internal fixation, persistent, usually low-grade drainage occurred and was controlled only by removal of the fixating agent, which was usually a plate and screws. If removal was unduly delayed, apparent healing might occur, but was likely to be followed by a breakdown of the wound and recurrent draining sinuses.

It is only fair to add that in many instances in which removal of the metallic material was necessary, the fractures had been severely displaced, and even when infection ensued, the plates had served the purpose of maintaining alinement of frequently badly comminuted portions of the shaft. Results in the tibia were far less satisfactory than in the femur, and the plates sometimes seemed to maintain distraction rather than contact. The hairline approximations usually obtained in civilian fractures treated by internal fixation were not possible in gunshot wounds, particularly fractures of the tibia caused by landmines.

VAUGHAN GENERAL HOSPITAL

Interesting comparative figures are available in a series of 163 fractures of the femur analyzed by Lt. Col. Ralph Soto-Hall, MC, and Lt. Col. Thomas Horwitz, MC, from the 30th General Hospital and Vaughan General Hospital in 1946 (*22*). Of these, 122 were treated by traction-suspension alone, and 41 (24 simple, 17 compound) by internal fixation (36 by plates and six screws each, and five by screws alone).

From the standpoint of infection, the best results were achieved when initial wound surgery was done within 24 hours. There was no infection, or only mild infection, in the 84 cases in which this timing is known to have been achieved. When early internal fixation was used, however, the incidence of severe infection was about 50 percent higher than when it was not, and plates and screws usually had to be removed before healing occurred. Results were better when only screws were used, as well as when fixation was accomplished through a separate longitudinal incision and not through the combat wound.

The immediate results of internal fixation, as in other reported series, were often gratifying, but the end results, also as in other reported series, were often described as "vicious." They included:

1. Distraction, which often appeared as the result of actual resorption at the bone ends, a normal finding in fracture healing. This complication was absent in transverse fractures, in which no rigid fixation device was employed and in which bony ends might continue to approximate, as in traction suspension. This complication was also not dominant in oblique fractures, which lend themselves well to multiple screw transfixions.
2. Occasional loosening of plates and screws.
3. Failure of callus formation on the side of the fracture adjacent to the foreign body. This complication was strikingly evident in many cases in which callus appeared in abundance on all other aspects of the fracture. The local failure of callus formation and the persistence of the fracture gap on the side of the plate were difficult to explain;

in no simple, uncomplicated fracture in which plates were removed was there any evidence of untoward reaction of the body tissues to the stainless steel foreign body.[2,3]

DELAYED FOLLOWUP STUDIES

Materials and Methods

The series of internal fixations analyzed in this chapter up to this point do not go beyond immediate results—seldom as long as a year—and such results provide no reliable information concerning the real value of this method. Much more significant are the data provided in such a long-term investigation as the one to be cited herewith (*25*).

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[2] Except for observation of a few prisoners of war released after treatment in German hospitals, whose Küntscher nails had to be removed because of infection, U.S. Army medical officers had no experience with intramedullary fixation in World War II (*23*).

To complete the record, however, it might be noted that this technique was an extremely important postwar development. A grant to investigate it was a joint project of the Army Medical Department and the National Research Council in 1947, and further impetus to research in this field was given when the Committee on Fractures of the American Academy of Orthopaedic Surgeons also adopted it as a project for investigation.

The applicability of this technique to battle casualties was discussed at the 1951 session of the American Academy of Orthopaedic Surgeons by Dr. Hampton, as follows (*24*):

No military experience with intramedullary fixation in battle casualties exists to serve as a guide for these recommendations, which are based on the World War II experience with combat-incurred compound fractures and on the postwar civilian experience with intramedullary fixation. There is no place for this procedure in a combat zone, but it could probably be utilized in the communications zone if the following criteria were met:

1. If base hospital facilities and equipment were adequate for major elective procedures.
2. If personnel were available to perform it who were experienced in the problems of bone and joint surgery in both combat and noncombat compound fractures and who were reasonably experienced in the techniques and pitfalls of intramedullary nailing.
3. If theater holding policies permitted staged procedures.
4. If the degree of comminution was not too great to preclude adequate stabilization by a nail. It was thought that about 20 percent of combat injuries would present location and contour suitable for this technique.

Intramedullary nailing would be the procedure of choice, just as in civilian surgery, in simple fractures, though simple fractures were not frequent combat injuries. In the light of current knowledge, intramedullary nailing should be performed in open and draining wounds only when special indications seemed to warrant the otherwise excessive risk of infection. Generally, it was better to close the wound, permit it to heal, and institute balanced suspension skeletal traction for 2 weeks or more before undertaking nailing.

Nailing might be considered at the first operation of reparative surgery, 5 to 10 days after wounding, if the following criteria were met:

1. If such massive soft-tissue loss had occurred that skeletal traction would be handicapped.
2. If multiple soft-tissue wounds had been sustained, perhaps associated with burns, of the same extremity or elsewhere.
3. If there had been severe skeletal injuries of other extremities.
4. If associated intrathoracic or intra-abdominal wounds required lifesaving surgical procedures.

Dr. Hampton, who had had a large experience with internal fixation in the Mediterranean theater in World War II, thought that any fracture of such a contour that plating was possible would certainly permit intramedullary nailing; nailing, in fact, could probably be done in open wounds with less risk of infection than plating, since surgical trauma and periosteal stripping would be less. He also stressed the potential value of this procedure in mass casualties.

One of the advantages of this technique was that transportation from overseas could be accomplished earlier, without the impediment of cumbersome apparatus. Nailing could be carried out in the communications zone in some cases with the idea that casualties thus treated could be restored to limited duty in a few months, and later to full effectiveness.

[3] This presentation deals with a technique not employed at all in World War II, and the restrictions theoretically imposed and the advantages theoretically to be gained have, therefore, no real basis of fact. There is no way of knowing what difficulties might be encountered if there were any large-scale attempt to employ intramedullary fixation on battle-incurred fractures. If the attempt were to be made overseas, the chances are that this technique would result in the same long-term infections that accompanied the use of internal fixation in World War II.—M. C.

This study was carried out in two parts, under separate contracts with the Research and Development Division of the Surgeon General's Office, Department of the Army. One part, which dealt with statistical data, was conducted by Mr. Seymour Jablon, statistician, Follow-up Agency, National Academy of Sciences, National Research Council. Mr. Jablon, assisted by Mr. A. Hiram Simon, was responsible for the development of rosters and the review of records. The other part of the study, which concerned the clinical aspects of the investigation, was conducted by Dr. (formerly Maj., MC) Joseph D. Godfrey, at the Buffalo General Hospital, assisted by other orthopedic surgeons in other areas of the country.

The study was conducted between 1 July 1955 and 30 June 1957; that is, 10 to 12 years postwar. It was limited to fractures of the femur, injuries which provide the widest field of usefulness for internal fixation. It included, in addition to the fractures treated by internal fixation, a comparable series of femoral fractures treated by balanced suspension skeletal traction. The special objectives of the investigation were to examine the end results of combat-incurred fractures of the shaft of the femur treated by rigid internal fixation with respect to anatomic, functional, cosmetic, and economic considerations.

The source material used in this investigation was derived from:

1. Army clinical records, made available to the investigators under the regulations that govern access to such records for scientific purposes.
2. Veterans' Administration claims folders, made available under the same regulations.
3. Listings of 224 femoral fractures in the possession of Dr. Godfrey, who had maintained them as the patients were encountered at the 23d General Hospital in Italy and France during World War II.
4. Questionnaires sent to the veterans selected for this study.
5. Followup examinations by Dr. Godfrey and other orthopedic surgeons.

The 11,712 punchcards covering admissions to Army hospitals in 1944 and 1945 with the principal coded diagnosis of compound fracture of the femoral shaft were reduced, by acceptable statistical methods and for other reasons, to 359 fractures in 354 patients; 78 of these fractures were included in Dr. Godfrey's 224 listings.

The essential data in these fractures were as follows:

1. Of the 359 fractures, 188 were treated by traction and 171 by internal fixation.

2. Of the 188 casualties treated by traction, 55 (29 percent) had associated injuries, as did 66 (39 percent) of the 171 treated by internal fixation.

The term "associated injury" was defined as a separate and distinct injury of the extremity in which the femur was fractured, or as a peripheral nerve or vascular injury in this extremity, or as a combination of these injuries. Injuries of peripheral nerves, usually the sciatic nerve, were present in 63 cases, additional wounds of the same extremity in 39, and

vascular injuries in 11. It was realized that the inclusion in the analysis of veterans with associated injuries would naturally complicate the assessment of results. In some instances, it was possible to say without qualification that a given residual impairment was the result of the femoral fracture or of the associated injury. In most instances, however, such judgments were hard to make, were at best arbitrary and subjective, and were, therefore, not attempted.

3. Of the 171 patients treated by internal fixation, 68 were managed by screws and 103 by plating and screws.

4. Of the 171 internal fixations, 56 were classified as necessary. The term was defined as meaning that roentgenologic evidence in 42 cases and evidence derived only from the charts in 14 cases indicated that management by traction was not possible. It was realized that the group included in this necessary category on clinical evidence, without roentgenologic confirmation, was subject to a larger error than the group in which such evidence was available, but the discrepancies proved insignificant. The cases in this group were chiefly those in which loss of bony substance at the level of the fracture made skeletal traction a secondary, not a primary, choice. It might be mentioned that the selection of the 108 serial roentgenologic studies used in this investigation required the examination of more than 700 sets of roentgenograms.

5. The seven amputations (one bilateral), selected from 381 records, were included on the ground that amputation might represent the end result of both skeletal traction and internal fixation.

6. In 28 cases, the original attempt at skeletal traction was abandoned or was supplemented by rigid internal fixation because of the difficulty or impossibility of obtaining good alinement of fragments with traction alone.

7. In all, 262 questionnaires asking for specific information about their current condition were addressed to men who were known to be alive, who had not suffered above-knee amputations, and whose present addresses were known. Of those not sent questionnaires, nine could not be located, eight were known to have died, and seven were known to have undergone above-knee amputations. The 213 replies received, almost 79 percent, were sufficient to eliminate any bias by the factor of nonresponse.

Questionnaires constitute a simple and inexpensive method of obtaining followup information, but they have obvious defects as compared with personal interviews and physical examinations. In many instances, the patient can furnish accurate and useful information, though various motivations may influence his replies, such as exaggeration of disabilities or fear of altering a pension rating. The degree of a man's intelligence also may affect the usefulness of his reply. Finally, there is certain information that cannot be secured by this method. All of these considerations were borne in mind when the data on the returned questionnaires were compared with the data secured by Army records, Veterans' Administration records,

and reports from participating surgeons, particularly with respect to knee motion and shortening of the extremity.

8. In all, 258 requests for examinations of these patients were made of 139 orthopedic or other qualified surgeons in various parts of the country, in addition to the 16 examinations made by Dr. Godfrey himself. The surgeons were supplied with the names and addresses of the men to be examined, and the men themselves were asked to make contact with special surgeons. A standard form was supplied for the examinations, and in selected cases, illustrating different methods of management, roentgenologic studies were also arranged for. The cooperation of the participating surgeons was excellent, but the response (106 examinations, 41 percent of those requested) was less than had been hoped for, undoubtedly because the followup process was so diffused that the continuing, persistent effort that alone can assure success in such a project simply did not exist.

Analysis of Data

Evaluation of therapy.—Careful examination of the clinical records of these 354 patients showed that, on the whole, their treatment had been excellent. Debridement was performed by the correct technique, traction was instituted correctly, and internal fixation was generally carried out by a standard, atraumatic technique. At all echelons, the importance of blood volume was realized and adequate amounts of blood were given before operation. Special attention was paid to the protein deficit that was so notable in fractures of the femur. A more-than-liberal amount of protein was included in the diet, and special care was taken to see that what was provided was ingested.

Echelon of operation.—Army regulations required that, to insure competent surgeons and proper equipment, internal fixation must not be performed forward of fixed hospitals. In this series, these regulations seem to have been generally obeyed.

Only eight of the 171 operations were performed in other than general hospitals (six in evacuation and two in station hospitals). Hospital facilities were not always utilized as originally planned, for logistic reasons, and it may be that these eight operations were done while the hospitals were serving in a fixed capacity, with holding periods long enough to make internal fixation practical as well as indicated.

Of the 188 fractures treated by traction, all but eight were treated in general hospitals (two in evacuation and six in station hospitals).

Date and theater of performance.—The proportion of these 359 fractures treated by internal fixation was considerably higher in 1944 (139, 55 percent) than in 1945 (32, 30 percent). The explanation is linked with the relative proportions treated by this technique in the Mediterranean theater (71, 73 percent) and the European theater (90, 37 percent). As explained in detail elsewhere (p. 377), internal fixation was rather popular in the Mediterranean theater during 1944. By 1945, its generally unsatisfactory

results in combat-incurred fractures had become evident in the Zone of Interior, and its use was discouraged if not actually forbidden in that theater. The operations performed in the European theater were done chiefly in hospitals coming up from the Mediterranean theater, before the theater policy had been disseminated to them.

There was no general policy in the Pacific Ocean Areas, also as explained elsewhere (p. 380); 10 of the 20 fractures in the series from those areas were handled by internal fixation and the other 10 by traction-suspension.

Level of fracture.—In the 170 internal fixations in which the information was available, 52 fractures were in the lower third of the femur, 28 at the upper third, and 90 in the middle third. In the 188 fractures in which traction-suspension was used, the respective figures were 51 for the lower third, 45 for the upper third, and 92 for the middle third. The greater preference for the use of skeletal traction in fractures of the upper third of the femur (62 percent, versus 38 percent for internal fixation) is natural, in view of the notorious difficulty of managing infected fractures in the proximity of the hip joint.

Associated injuries.—Skeletal traction, as already mentioned, was used in 55 of the 121 fractures with associated injuries and internal fixation in 64. The preference for internal fixation in these circumstances is explained by the fact that it permitted earlier treatment of the associated problem, which was particularly important in associated nerve injuries. Only three of the 11 associated vascular injuries were treated by internal fixation; most surgeons were unwilling to run the risk of additional trauma to an extremity in which the vascular supply was already impaired.

Timelag.—The timelag from wounding to debridement was not influenced by the kind of definitive treatment instituted later, as one would not expect it to be. It should be pointed out, however, that in all but 28 of the 351 patients for whom this interval was known, initial wound surgery was done within 48 hours after wounding. This is a performance that speaks well for the quality of medical care these casualties received and for the medical organization that provided it.

The timelag from wounding to definitive care ranged from less than 4 days in 19 cases (10 managed by internal fixation) to 30 days or more in 47 (37 managed by internal fixation). When there was no associated injury, the average timelag between wounding and the institution of traction was 12.4 days in 129 stated cases as compared with 10.0 days in 69 cases managed by internal fixation. When there were associated injuries, the average timelag in 58 cases treated by traction was 16.1 days and in 102 cases treated by internal fixation, it was 27.4 days.

Evacuation and hospitalization.—Casualties treated by traction were held overseas slightly longer (about 21 days) than those treated by internal fixation. At the end of 4 months, about 90 percent of patients without associated injuries had been evacuated, against 76 percent of those with

associated injuries treated by traction and 89 percent of those treated by internal fixation.

For the total series, the average stay in hospital for patients without associated injuries was 13.9 months, against 20.3 months for those with associated injuries. The presence or absence of such injuries, not the type of treatment instituted, explains these figures.

Subsequent hospitalization.—This investigation showed that 223 of the patients involved had no postwar history of hospitalization. Of the remainder, men who had been treated in traction, whether or not they had associated injuries, had the fewest readmissions and men treated by plating had the most. This is a situation which could have been anticipated: The more foreign material present in the wound, the more likely was trouble, chiefly infection, to develop.

Response to questionnaires.—Attention has already been called to the fallacies inherent in the use of questionnaires for the procurement of clinical information. The following data, thus obtained, should be interpreted with their source in mind.

The greatest response was obtained from men with associated injuries (81 questionnaires, 70 replies, against 143 replies to 181 questionnaires from men without associated injuries). Also the chances of a response seemed to vary with the amount of foreign material in situ (80 returns from 94 questionnaires in the fixation group versus 133 returns from 168 questionnaires in the traction group). The explanation of both proportions is obvious.

Infection.—With drainage used as the criterion of infection, there had been no drainage at all in 62 of 125 cases treated by traction without associated injury and none in 27 of 54 cases with associated injury. In the cases without associated injuries treated by internal fixation, there had been no drainage in 20 of 36 cases treated by screws and none in 24 of 28 treated by plating. In the associated injury group, drainage had been present in 11 of 12 cases treated by screws and in 19 of 25 treated by plating. Only fractures without associated injury and fixed only with screws compared favorably with the cases treated by traction.

It is remarkable that infection was absent in so many cases in this series (116 of the 280 cases in which the information was available), and highly significant that it was present in the great majority of cases in which internal fixation was used, particularly when plates were used.

Fifty of the patients who replied to the questionnaires failed to answer the question about drainage. From the replies that were received, it seemed that 12 patients had never had any drainage, three were still draining, and most of the others had had no drainage after the third or fourth year postwounding. In an occasional case, drainage had lasted as long as 8 years. The fact that drainage ended in such relatively short periods, and had never been present in so many cases, constitutes another tribute to the excellent surgical care these patients had received.

Prolonged drainage was a frequent indication for the late removal of fixation agents, particularly plates. Results of removal were generally good, but were not always prompt. The replies to the questionnaires on this point were unfortunately incomplete, but it was possible to determine again that large foreign bodies are not well tolerated.

Self-evaluation of current status.—Replies to the various questions on the questionnaires produced the following self-evaluation of their current status from the patients under investigation:

1. In the group without associated injuries, the type of treatment that had been used seemed to make little difference. Men with associated injuries, on the other hand, were more inclined to describe their health as fair or poor than men without such injuries. The poorest showing was made by men with associated injuries who had been treated by plating; 57 percent of this group considered their health fair or poor, while the highest proportion in any other category was 40 percent.

2. In respect to pain, men with associated injuries who had been treated by plating also had more complaints than men in any other group. Most men in all groups stated that the injured leg tired more quickly than the other.

3. About half of the men in each category stated that an occupational change had been required because of problems connected with their injuries.

4. None of the men claimed inability to walk, but a substantial number stated that they were unable to run, climb, or squat. The largest number of complaints came from men who had been treated by plating. Those treated by traction and those treated by transfixion screws without associated injuries were fairly comparable in all regards. The chief difference was a lessened ability to climb on the part of those treated by traction. Men treated by plating seemed able to squat or climb more readily than those treated by traction, but they were less able to run. None of these figures are impressive because of the very small size of all samples.

5. The most important residual disability to be reckoned with in all fractures of the femur is loss of motion at the knee joint. Inability to straighten the knee was claimed in their replies by 21 to 38 percent of these patients. Their statements varied with the method of treatment and the presence or absence of associated injuries. The figures in each category are too small to be significant, but as usual, plating gave the highest proportion of poor results. Oddly, this disability was not reported by any of the seven men with associated injuries who were treated with screws.

6. The relation of knee motion to ability to work varied. It is somewhat surprising that men with associated injuries did not claim more disability than men without such injuries.

7. It is interesting to compare the degree of inability to bend the knee claimed by the men who replied to the questionnaires with the objective reports by the surgeons who examined 105 men from this standpoint.

The patients, as might have been expected, usually reported more disability than the examiners, but the results were not widely different: The data coincided in 57 cases, 39 men reported less ability than the examiners found, and only five reported more. In four of the remaining cases, the comparison was impossible, and one patient is omitted from the tabulation because a second fracture of the femur in civilian life disabled him far more than his battle-incurred injury.

Some of the discrepancies just mentioned may be explained by the misunderstanding inherent in all collections of data by questionnaires. It may be that the patients thought of knee bending in terms of what could be achieved on voluntary (active) motion, as opposed to the examiner's interest in active assisted or passive motion. Another fact to be borne in mind in evaluating these results is that examinations by different persons, even when the examiners are experts, often produce variable results.

8. Figures for shortening of the injured extremity again indicate the excellent care these men had received. According to their questionnaires, 69 had no shortening and 88 others, shortening of less than an inch. Men treated by screws reported less shortening than those treated by traction or by plates. Shortening of an inch or less is not usually a serious handicap (and sometimes may be preexistent), while to try for perfect length introduces the risk of distraction and nonunion.

Discrepancies between the shortening reported by the patients and that reported by the examiners were slight: 12 of the 105 men examined reported greater shortening and 12 reported less. In the remaining cases, the observations coincided.

Internal Fixation After Failure of Traction

For reasons of statistical selection, not necessary to go into here, the 28 cases in which internal fixation was used after failure of traction were divided into one group of five cases and another group of 23 cases.

Good functional results were obtained in two of the five cases in the first group. In the third case, a peroneal nerve paralysis was in large part responsible for the patient's permanent disability. The fourth patient, who had a sciatic nerve injury also, was doing reasonably well in traction until the femur was refractured in an attempt to induce knee bend. The plate and screws used in secondary internal fixation had to be removed because of infection and the patient continued to have recurrent bouts of osteomyelitis. The functional result in this case was poor, but because the man's work was sedentary, the leg was not an economic handicap. In the remaining case, the patient, after his discharge from the Army, had a series of misfortunes, including a refracture of the femur, a knee injury, complete transverse fractures of the tibia and the fibula a refracture of the tibia, and a second refracture of the femur originally injured. A reasonably satisfac-

tory functional result had not been obtained when this man was discharged after his first injury, and his subsequent misfortunes can probably be attributed, at least indirectly, to that error.

The investigators made the following comments on the other 23 cases in which internal fixation was used after failure of traction:

1. The usual reason for failure of traction was misalinement or displacement of the fragments. Internal fixation offered the only means of correction. These difficulties were stated explicitly in 18 cases. In another case, the reason was inclusion of scar tissue between the fragments. In the other four cases, the reasons for failure were not clear.

2. Fixation was done, on the average, after 4 weeks of traction. The range was from 1 week to 10 weeks.

3. In seven instances, the femoral fractures were complicated by nerve injuries, five sciatic and two peroneal. Amputation was necessary in one of these cases, and in one, in which the sciatic nerve had been partially severed at operation, an excellent functional result was obtained.

4. Osteomyelitis, which was present in six cases, cleared completely in five when plates and screws were removed. The remaining patient was left with chronic recurrent osteomyelitis.

5. In six of these 23 cases, the end result was good to excellent. In seven cases, four with neurological complications, the result was poor. In the other 10 cases, the result was fair; the patients could walk, stand and squat to some degree, but they had moderate limitation of knee flexion, shortening of the leg, or both.

Veterans' Disability Awards

Information was available in 278 of the 354 cases in this series concerning disability compensation awards by the Veterans' Administration. Three men, all treated by traction, received no payment. Two had associated injuries, and the other, without associated injuries, filed no claims.

Among men without associated injuries, the most notable feature of this phase of the study was the tendency to award those who had been plated with 40 percent or more disability payment. Only two of the 28 in this group received less than that amount, and three received from 70 to 90 percent, as did 10 of the 23 men in the parallel group with associated injuries.

The award of disability payments of necessity rests in part on the past history, but to what extent the mere knowledge that a man has a metal plate in his leg influences rating boards, it is not possible to say. Be that as it may, the figures present evidence of the financial burden placed on the Government in consequence of these injuries and in relation to their methods of treatment. How indicative the awards are of the true residual disability in each instance, it is again not possible to say.

Amputations

The reasons for the inclusion in this series of seven amputations (in six patients) have already been specified. Two were performed for vascular indications (one managed by traction and one by traction and plating), one for gas gangrene (managed by traction), one for a nerve injury (managed by traction and then by plating), and one for nonunion and osteomyelitis (managed by traction and two bone grafts). The bilateral amputation was performed as a primary procedure.

The followup study revealed nine subsequent amputations, four below and five above the knee, and all with associated injuries. Skeletal traction had been used in four of these cases and internal fixation (in three instances with plates) in the other five.

Conclusions

One very interesting feature of this report is the conclusions arrived at separately by the two investigators. Reached statistically by one investigator (Mr. Jablon) and clinically (supplementally by statistics) by the other (Dr. Godfrey), the conclusions are remarkably similar, and no attempt is made to differentiate them in the following summary:

1. The role played by clinical judgment in the selection of treatment for fractures, as for all other conditions, is large, and retrospective comparisons of treatment are never safe since it cannot be guaranteed that the cases submitted to the several forms of treatment are, in fact, comparable except for differences in treatment. Definitive comparisons of alternate forms of treatment require suitably randomized experiments, and an attempt was made to set up this study on that basis.

2. The diversity of compound fractures of the femur precludes a single, ideal method of treatment. In this investigation, hindsight revealed some instances in which management by skeletal traction might better have been replaced by management by internal fixation, and vice versa. It also revealed some instances in which internal fixation achieved good results after traction had failed.

3. In general, evacuation to the Zone of Interior was possible sooner after fixation than after traction, on the average about 3 weeks, but the total average duration of hospitalization was not influenced materially by the type of treatment employed.

4. The presence or absence of associated injuries, especially of nerve injuries, was of overriding importance in the end results.

5. In fractures without associated injuries, in which the surgeon presumably felt that he had a free choice of management (except as constrained by Army policies), internal fixation had apparently little to offer:

a. A man whose fracture was fixed was evacuated from overseas a little sooner than, but he remained in the hospital about as long as, a man treated by traction.

b. He drew at least as much disability compensation from the Veterans' Administration.

c. He was more frequently readmitted to the hospital for treatment of sequelae of his injury, especially osteomyelitis.

d. He complained about as frequently of pain as the traction-treated patient.

e. He was less likely to be able to run than the man treated by traction, though more likely to be able to climb or squat.

f. He had about the same amount of knee motion and about the same amount of residual shortening.

g. He was much more likely to have a continuation of drainage for many months than a man treated by traction, though it usually ceased when the metal fixation agents were removed.

6. The percentage of infection was higher in the fractures fixed internally, particularly when plates were used, than in those treated by traction.

7. Hospital readmissions were much more frequent in the cases treated by plating. Cases treated by traction and by screw fixation were about the same in this respect.

8. Good results frequently were not achieved in fractures treated by fixation until the foreign material was removed. Plates had to be removed more often than screws.

9. Better results were secured with internal fixation if it was delayed until the wound was well healed and all evidence of infection had disappeared.

10. This investigation shows that there is a definitive place for internal fixation in the management of combat-incurred injuries of the femur, though its field of usefulness is limited. In a few carefully selected cases, it is the treatment of choice.

11. On the whole, the treatment of choice for battle-incurred fractures of the femur is skeletal traction. If internal fixation is substituted for it, it must be with a full recognition of the complications and risks associated with this technique.[4]

[4] This Editor, as Senior Consultant in Orthopedic Surgery in the European theater in World War II, is constrained to make certain personal comments on this report, if only because he had the unenviable task of informing many highly competent orthopedic surgeons in hospitals which had come up from the Mediterranean theater that internal fixation could no longer be performed in them. This was a logical prohibition. In any mass care of battle casualties, some of it, of necessity, will be rendered by surgeons of limited experience. Internal fixation was sometimes performed by such surgeons, even after the prohibition against it had gone into effect. It could not have been otherwise. There were ultimately 146 general hospitals in the European theater, not more than 30 of which were affiliated units. Orthopedic talent in this theater was necessarily spread rather thin. It is well that the experiment of internal fixation was carried out in the Mediterranean theater, which had a large proportion of affiliated units.

It is also well that this followup investigation was conducted by an experienced orthopedic surgeon, who had himself performed many internal fixations. It makes his conclusion, that skeletal traction is the treatment of choice in combat-incurred fractures, far more significant than it might otherwise have been.

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The conclusion of the whole matter is that in military surgery the simplest method is always the best. Open reduction and internal fixation constitute a procedure that is almost never indicated overseas. The situation is entirely different after wounds have healed and 6 months or more have elapsed since wounding. Then corrective osteotomy, bone grafting, and internal fixation may be employed with far less risk of infection and with far greater chances of success.

The complete reports from which this summary was made are on file in the General Reference and Research Branch, Historical Unit, U.S. Army Medical Department, Walter Reed Army Medical Center, Forest Glen Section.—M. C.

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CHAPTER XIII

Bone Grafts

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HISTORICAL NOTE

Autogenous bone grafting in U.S. Army hospitals in World War I was usually a postwar procedure. In May 1924, Maj. (later Maj. Gen.) Norman T. Kirk, MC, presented before the American Orthopaedic Association an analysis of 158 bone grafts (*1*), 129 of which were the basis of the account of bone grafting in the official medical history of World War I (*2*).[1] In January 1938, Colonel Kirk presented a summary of the basic principles of bone transplantation for nonunion before the American Academy of Orthopaedic Surgeons (p. 403) (*3*). These three presentations, by an expert orthopedic surgeon with particular competence in this field, furnish a useful background for the account of bone grafting in World War II, when the operation was part of the wartime management of ununited fractures. The operations reported by Colonel Kirk, all performed without the benefit of antibiotic therapy, also furnish an interesting contrast to bone grafts in World War II, when adjunct therapy was an important part of the routine of management.

The 158 operations reported by Major Kirk in 1924 (*1*) were performed on 135 patients. There were 27 successes in the 29 grafts performed on 28 patients with simple or compound fractures without infection. In the other 129 operations, performed on 107 patients with infections, there were only 76 successes.

The circumstances in the second group of cases were generally unpropitious. Severe damage had been sustained by the bone and the adjacent soft parts. Destructive infection[2] had been present for periods varying from 4 months to more than 2 years. Previous unsuccessful surgery included 26 bone grafts, 15 plating or wiring operations, and six "stepping" (step-cut) operations. Pathologic findings included osteoporosis; atrophy, arising from the injury and infection and from disuse; scar tissue; impairment of the local circulation; and reduction of the reparative osteogenetic properties of the bone. In eight cases, the entire shaft of the humerus was destroyed except for a couple of inches at each end.

Techniques included inlay grafts (115 operations, 78 successes); intermedullary (intramedullary) grafts (33 operations, 17 successes); osteoperiosteal grafts (seven operations, five successes); and two peg (not intermedullary) grafts, both of which

[1] This chapter does not carry an author's name, but internal evidence clearly indicates that it was prepared by Major Kirk.

[2] Major Kirk reluctantly went along with the term "osteomyelitis" because it was in common use. His preference was for osteitis.

were successful. The single transplant also was successful. In a number of instances, a second attempt at grafting gave good results.

Grafts generally were cut at least three times the length of the deficit to be bridged or of the damaged bone with which the graft would be in contact. Kangaroo tendon and chromic catgut gave such poor results, and required removal so often, that the grafts were all made self-retaining.

Criteria for grafting included:

1. Healing, without signs of infection, for at least 6 months.
2. Roentgenologic evidence of absence of bone infection or sequestration.
3. No recrudescence of infection after repeated vigorous massage by a physiotherapist.
4. Uncomplicated healing after excision of scar tissue in the skin, soft tissues, and about the bone ends, followed by skin closure. If healing was per primam, the graft was applied 4 to 6 weeks later. If infection occurred after the first operation, another 6-month delay was required. Even with these precautions, infection caused 22 failures in the 129 complicated cases, and severe infections occurred in nine others, in which union eventually occurred. There seemed no sure way of determining when the risk of latent infection had passed; very severe infection, with consequent failure of the graft, was encountered in one case a year after healing of the original wound, when there had been no reaction at all after preliminary scar excision.

The distribution of operations and the results in 134 followed-up patients were as follows:

Eighteen successes in 33 operations on the humerus.

Eleven successes in 16 operations on the radius.

Nine successes in 10 operations on the ulna.

Four successes in six operations on the radius and the ulna. In one instance, operation on the radius only was successful, which means that in this group there were only seven successful single operations.

Three successes in six operations on the femur.

Fifty successes in 60 operations on the tibia; in one instance, the injuries were bilateral.

Both operations on the patella were successful, as were single operations on the clavicle, metacarpus, and metatarsus. More than one attempt was necessary in 16 cases (four operations on the humerus, two on the ulna, nine on the tibia, and one on the patella). Several successes were achieved in highly unpromising cases, including one in a patient who pleaded for bilateral amputation. It is more than possible that, in some cases classified as failures, bony union occurred after the patients were discharged; this is known to have happened in two cases and may have happened in more.

Infection, as already mentioned, was responsible for 22 of the 53 failures. Atrophy was responsible for 15 failures; fracture in plaster before the seventh month for eight and after the seventh month for seven; and faulty fixation of the patella for one.

The single death occurred in a graft of the upper third of the femur and was caused by surgical shock. As was the routine, blood pressure readings were taken every 10 to 20 minutes during all such operations, because these patients, after long periods of hospitalization, multiple surgery, and absorption of toxins from chronic infection, readily went into shock. "When it [shock] occurred, it was treated with saline intravenously and blood transfusion." In that single sentence are one of the major differences between the management of these patients in World War I and World War II and one of the major explanations of the greater success of bone grafting and all other surgery in World War II.

Early weight-bearing and unnecessary strain were the supplementary causes of some of the failures in this series, but some occurred simply because the osteogenetic power of the bone was at the zero point.

In the discussion that followed Major Kirk's presentation in 1924 before the American Orthopaedic Association, Dr. Fred H. Albee (formerly Col., MC) recalled that he had worked with him at General Hospital No. 3, Colonia, N.J., in World War I and had followed some of the patients in this series there. Later, he had observed others in the series at Walter Reed General Hospital, Washington, D.C. He believed their management to be sound in every particular.

In his presentation before the American Academy of Orthopaedic Surgeons in January 1938, Colonel Kirk (*3*) outlined the following principles of bone grafting. They were essentially those in effect when the United States entered World War II:

1. Nonunion of fractures is presumed to exist at the end of 6 months after injury. The accepted treatment for it is autogenous bone grafting.

2. In spite of the many other theories advanced to explain the process, it seems reasonable to assume that a bone graft acts primarily as a means by which circulation of the blood is established between two un-united bone fragments. When this happens, union follows.

3. Types of grafts include inlay, onlay, osteoperiosteal, and massive. Multiple bone chips may also be used as grafts. Massive grafts are indicated in the presence of such marked bone atrophy that neither onlay nor inlay grafts are practical. The peg type of intramedullary graft, like the beef-bone peg graft, has no place in the treatment of nonunion.

4. Grafts may be secured from the inner surface of the tibia, the crest of the ilium, or the fibula. If necessary, the entire fibula may be used, one end at a time, to replace lost substance in the adjacent tibia.

5. Grafting must not be attempted in infected injuries until at least 6 months after the wound has been thoroughly healed and roentgenograms are negative for sequestra and other bony abnormalities.

6. The preparation of the bed for the graft is important. Scar tissue between the bone ends must be removed, the bone ends freshened, and the medullary canals of both fragments opened. At least the outer third of the cortex must be removed, so that the blood supply of the bed will be derived from the medullary circulation and will not be limited to supply from the periosteum.

7. Scar excision combined with wound closure, by such measures as may be indicated, including pedicle graft, should be carried out before grafting. If latent infection is not lighted up by these procedures, and if radiant heat and massage over a 2-week period also cause no reaction, grafting may be proceeded with.

8. Avascular bone is best removed, even though the procedure results in loss of bony substance. The blood supply cannot be reestablished through avascular bone, and regeneration is, therefore, impossible.

9. Whenever it is mechanically feasible, the graft should have twice as much length of contact with the normal bone in each fragment as the length of lost substance or abnormal bone to be bridged.

10. Self-retaining grafts have replaced kangaroo tendon and chromic catgut, which frequently did not absorb and which, by acting as foreign bodies, caused sinus formation.

11. Experience has indicated that the massive onlay graft is preferable for the humerus, radius, ulna, and femur, and the massive inlay graft for the tibia. Self-retaining grafts provide ideal fixation.

12. Plaster fixation is essential after bone grafting. Casts are changed as soft-tissue atrophy occurs until roentgenographic examination shows that the graft has become an integral part of the bone. This will take two or three times as long in old compound fractures, with impaired circulation, as in fresh, uncomplicated fractures. A properly fitted supporting brace is then worn until union is firm.

GENERAL CONSIDERATIONS OF BONE GRAFTING

Certain general statements can be made about bone grafting in World War II:

1. The mere existence of nonunion or loss of bone substance was not, in itself, regarded as an indication for grafting. Grafting was always a procedure that required very careful consideration before it was adopted.

2. Each patient selected for a bone graft was regarded as an individual, with special problems. He was then treated by the least complicated method likely to obtain the best end results, in the shortest period of time, with a minimum of risk.

3. Successful bone grafting was based on the previous provision of a clean wound and a vascularized bed. If they had not been provided, amputation would have been necessary in many large bony defects, as it was in many such cases in World War I. On the other hand, had both surgeon and patient known what lay ahead of them in many cases, they might have elected amputation as the wiser choice in the beginning (p. 385).

4. Any new technique purporting to be better than existing techniques must be simple and uncomplicated, easy to use, applicable to large groups of casualties, and readily performed. It must also give results as good as, or better than, the results being achieved with techniques already in use.

5. Most orthopedic surgeons were in general agreement about the timing of bone grafts. No surgery at all was undertaken during periods of active infection. The usual period of delay after cessation of drainage and complete wound healing was from 3 to 6 months, with most surgeons favoring the longer period, on the ground that, while penicillin had reduced the optimum waiting period, a delay of considerable length was still necessary for clinical observation. The whole question of surgical timing is discussed in greater detail in the chapter on osteomyelitis (p. 293).

6. Bone banks did not exist in World War II. At Thomas M. England General Hospital, Atlantic City, N.J., the amputation center made much fresh homologous bone available to the Orthopedic Section, and its chief,

Maj. R. Nelson Hatt, MC, performed many grafts with it, with excellent results. His work was done before the concept of bone banks was developed.[3]

7. Preoperative preparation for bone grafting was extremely important. It is discussed in the chapter on osteomyelitis (p. 296).

8. The grafting techniques used during World War II were chiefly those Colonel Kirk had described in 1938:

a. Onlay grafts. They were easily applied, but required metallic fixation for good stability.

b. Inlay grafts. To immobilize the extremity properly they had to fit perfectly. To achieve such a fit was often a difficult procedure, particularly when there was much loss of bone substance. Metallic fixation was also required with inlay grafts.

c. Intramedullary grafts. They provided excellent fixation, but were technically difficult to apply; they became less popular as time passed because the poor results often obtained with them were believed due to their obliteration of the medullary cavity.

d. Self-retaining grafts. They provided correct immobilization of fragments and could be fixed in place without the use of screws or plates.

e. Various combinations of these techniques.

HEALING OF BONE GRAFTS

Two considerations are involved in all bone grafts, (1) the healing of local soft tissue (p. 405) and (2) the healing of the graft itself.

The natural powers of healing are so great that in all wounds, once local resistance to invasive infection is established, some untoward circumstances are necessary to inhibit healing (*4*). When viable tissues are brought into absolute contact with each other, healing tends to occur even in the presence of infection. These generalizations apply to osteomyelitis as it was observed in World War II. After debridement, healing of soft tissue could be accomplished by delayed primary wound closure, as it was developed in the Mediterranean theater or by late plastic closure (*5*).

An infected wound could not be closed successfully unless all dead spaces were obliterated. Here, however, regional difficulties arose. Dead spaces could be obliterated by the use of soft tissues in areas in which sufficient such tissue was available, as in the femoral shaft. The circumstances were different in wounds of the femoral condyles, the tibia, and the feet, in which it was not available.

If the cavity was large, grafts might not be vascularized in the central portion and might become necrotic. If these necrotic portions were removed,

[3] This editor does not share the opinion of those who believe that many more bone grafts, many more of which would have been successful, would have been performed in World War II if bone banks had been available. He believes that the successful operations would have been far fewer, basing his opinion on the amply proved good results with autogenous bone as compared with material secured from bone banks.—M. C.

the peripheral portions of the graft would still granulate, and the wound and the bony defect, being smaller, would present fewer problems. Large cavities in cancellous bones of the feet were often successfully filled in with grafts, but the paucity of soft tissue in the feet, and the poor circulation in such soft tissue as there is there, always resulted in considerable delay in healing, even when grafts were fully incorporated.

Serial observations on 42 grafting operations at Battey General Hospital, Rome, Ga., by Lt. Col. Frank G. Murphy, MC, produced the following facts (*6*):

1. For 3 to 5 months after its insertion, a graft undergoes a process of atrophy, as evidenced by the increased radiolucency observed in roentgenograms; by accidental fracture after the lapse of considerable time; and by a sense of weakness in the grafted area, which persisted for several months. Clinically, the atrophic process was reflected in this series in increased fragility and secondary fractures in several patients, and in absorption of a portion or the whole of the graft in several others.[4]
2. When the graft is implanted, it does not possess osteogenetic power, but it may take on this property later, or after a process of reconstitution has occurred, as shown by union of a fractured graft after long immobilization.
3. Proliferation of bone, as demonstrated in late roentgenograms, seems to arise from adjacent fragments. The bone-forming process apparently extends along the graft at some time after so-called reconstitution of the graft. Later, the graft itself increases in size.
4. No evidence was obtained in this series to support the belief that the intramedullary portion of a graft causes atrophy or deterioration of the fragments into which it is implanted.
5. The maximum period of weakness in a graft seems to be between 3 and 6 months after its insertion. Roentgenographic studies in this series showed that the convalescent period necessary for a graft to become strong enough to assume function safely was much longer than previously estimated, though the time varied from person to person, in different locations, and in different placements of the graft.

SELECTION OF SOURCE MATERIAL FOR GRAFTS

Planned Studies

One of the important orthopedic studies carried out during World War II was under the auspices of the National Research Council and the University of California Medical School, San Francisco, Calif. It consisted of a planned experimental and clinical evaluation of cortical versus cancellous bone as grafting material. It covered a period of 3 years and was carried out by Dr. LeRoy C. Abbott and a group of his associates (*8*).

Experimental observations.—The experimental observations were based on five studies, all carefully controlled:

[4] Observations elsewhere by Lt. Col. Peter-Cyrus L. Rizzo, MC, and Capt. Otto Lehmann, MC, concerned an area of rarefaction about the intramedullary portion of a graft at the end of 3 months (*7*). This phenomenon had disappeared at the end of another month, and after 6 months, the outlines of the graft were scarcely seen.

1. Cortical defects in the shaft of the tibia in rabbits were filled in by grafts of both cancellous and cortical bone.

2. Defects created by complete resection of a segment of the mid shaft of the radius in rabbits were filled in by grafts from the cancellous portions of the ilium, a rib, or the cortex of the tibia.

3. Excision of the knee joint in dogs was repaired by grafts of cortical and cancellous bone.

4. Split spinous processes in dogs were treated by replacement by iliac bone, cortical bone, and bone from a spinous process or a rib.

5. Transverse osteotomy of the tibia in dogs was treated by replacement by cancellous iliac bone at the surgical site.

Studies included the examination of:

. Gross and microscopic specimens from eight iliac grafts removed in part or in toto from 11 days to 3 years after insertion.

2. Various cortical grafts.

3. An osteoperiosteal graft in the spine.

4. Material from the site of a Hibbs' spinal fusion and from a graft bed.

Conclusions.—As a result of these investigations, the following conclusions were reached:

1. There is no great difference in the behavior of fully matured bone elements, whether they are derived from cancellous or compact (cortical) bone. Once transplanted, they do not usually survive. The mass they constitute is so inert that it does not provide even a foreign body reaction, and sooner or later it will be replaced by the process termed "creeping substitution." This process, which is very slow, extends over many months, "with a gradually subsiding impetus."

2. In any graft, whether it be cancellous or cortical, the only elements that survive and that possess any degree of osteogenetic power are the cells that constitute the endosteal layer. The same generalization holds, though to a somewhat lesser degree, concerning the elements of the cambium layer of the periosteum.

3. The observations just stated are the fundamental considerations in bone grafting, and once they are appreciated, the relative merits of cancellous over cortical bone grafts are immediately apparent.

4. In cortical bone, the major portion of the graft is entirely made up of mature osseous elements. The endosteal layer is either absent or scantily present. Since the mature elements of the graft do not survive, the graft exists simply as an internal splint, which can serve even in that capacity only for a limited time. Before such a graft can be totally replaced by living bone, its mass must be entirely removed by (a) revascularization, (b) the leaching out of mineral elements, and (c) autolysis of the collagenous scaffolding. The process is necessarily slow because of the physical properties of cortical bone. The only pathways in the graft for the ingress of new blood vessels are small haversian canals and the surfaces immediately in contact with the graft bed. The formation of new vessels, furthermore, reaches the critical point within a few days after the trauma of

surgery and starts to decline thereafter, as biochemical conditions change. As a result, the progress of penetration is choked off, and, as a further result, many regions of the graft remote from the vascular bed may never obtain a vascular supply. The cellular elements of the capillary tufts possess considerable osteogenetic potentialities, but osteogenesis cannot occur without an accommodation space, which is not available in cortical bone until the original collagenous elements have been removed to provide for it. In a sense, therefore, the paradoxial situation exists that the graft is an actual deterrent to new bone formation, which can occur only on its surfaces, with the result that cortical grafts frequently become incorporated in the new bone and do not replace it.

5. In cancellous bone, the situation is different. The mature elements of trabeculae behave in much the same manner as those of cortical bone, with one highly significant exception, that every trabecula has an endosteal surface of great osteogenetic power. In addition, there are numerous bone marrow spaces. Bone marrow cells undergo rapid degeneration and provide wide channels, initially for the invasion of new vessels and eventually for the accommodation of newly formed bone. It is thus possible for the cells of the endosteum to come rapidly into contact with a vascular bed, with two results, (a) that they survive, and (b) that early proliferation and establishment of new bone are possible. It is characteristic to find in cancellous bone grafts, new trabecular elements and old elements that have become incorporated in them. These old elements, which are small and lie in very close relation to vital elements, are removed and replaced more rapidly, although they may remain in situ for many months before complete substitution occurs.

6. There is some difference between cancellous bone in which the marrow is extremely fatty and that in which red marrow predominates. Fat has an inhibitory effect on the formation of new vascular tufts, and when it is present in excess, bone formation is retarded. This observation explains the superiority of grafts of iliac bone or other bone containing red marrow over the fatty cancellous bone found in such areas as the lower end of the femur or the upper end of the tibia.

7. All that has been said in the foregoing paragraphs can be summed up in the simple statement that cancellous bone presents, as cortical bone does not, a very extensive endosteal surface and numerous accommodation spaces that allow for osteogenesis.

8. These distinctions were "most exquisitely" seen in this study in the grafts derived from the ribs, in which both compact and cancellous bone are present. An additional advantage of the investigation of such grafts was that both processes could be observed in the same patient under identical conditions. It was striking to observe the rapid formation of new osteogenetic tissue about the trabeculated elements of the grafts in comparison to the slow and restricted process of creeping substitution in the cortical portion.

Paste suspension grafts.—Another piece of experimental work carried out during the war but not concluded in time to be applied clinically was the use of ground bone by Capt. Ludolf J. Hoyer, MC, at Hoff General Hospital, Santa Barbara, Calif. The work, which was done on rabbits, consisted of the replacement of excised long bone material as chips in one extremity and as a ground paste suspension in the other.

In all the experiments, production of new bone from the ground-up bone was greater than the production from bone chips. The explanation was the ease of vascularization of the bone suspension as compared with the time-consuming resistance to vascular invasion of a solid mass of bone.

The suggested procedure, although it has been used only occasionally since the war, has a number of advantages: It involves less handling of bone and, therefore, offers fewer opportunities for breaks in the asceptic technique. It reduces surgical time. It also results in economy in the donor area, since production of new bone from ground-up bone, as just noted, was always greater than from bone chips.

Clinical Experiences

Progress reports on the work at the University of California published during the war, together with the dissemination of the information by consultants in surgery and orthopedic surgery, made the observations just described on the advantages of cancellous bone readily available to orthopedic surgeons, who came, in general, to accept the experimental results because their own clinical experiences bore them out.

The essence of the wartime controversy over the use of tibial versus iliac bone for grafts was that, while iliac bone was more readily revascularized and incorporated into the host bone because of its cancellous nature, the tibial bone had the advantage of being so rigid that it provided good internal fixation for a damaged bone fixed to it. What the iliac bone lacked in rigidity, however, was more than compensated for by its osteogenetic properties and the ease with which it could be secured without damage to the donor bone. The most serious disadvantage of tibial grafts, aside from their slow incorporation into the host bone, was the weakening of the sound bone that resulted in patients who already had unilateral inadequacy of the extremity. Fractures through the donor bone were not at all uncommon, and the incidence of fractures through tibial grafts was also fairly large, as might be expected, since the point of maximal stress on any fixation material is at the fracture site.

Material from the ilium used for grafts consisted not only of transplants for onlay grafts, but also of chips and slivers. Removal of a considerable portion of the wing of the ilium was often necessary, but, even when both crests were used as donor bone, there was no recorded instance of limping or any other ill effects.

The use of grafts from the fibula also gave rise to discussion. Refracture was possible unless extremely accurate contact was obtained and maintained between the graft and the fracture fragments; it was essential that healing occur not only between the onlay portion of the graft and the fragments but also between the fragments and the portion of the graft mortised in between them. Since fibular grafts were more slowly revascularized than tibial or iliac grafts, a longer period of immobilization was necessary when they were used.

Many orthopedic surgeons were not at all enthusiastic about the use of fibular grafts in the forearm. The result, early in the wartime experience, of transplantation of a fibular segment to replace a large ulnar defect convinced the group at Halloran General Hospital (Staten Island, N.Y.) that the fibula should be used for grafting only in large tibial defects of the same extremity. A successful experience with fibular grafts is related later in this chapter (p. 423).

CLASSIFICATION OF FRACTURE RESULTS

Most orthopedic surgeons used only two classifications of unfavorable fracture results:

1. The fracture did not unite. If union had not occurred within [illegible] months of the original injury, nonunion was considered to exist.

2. Healing was slower than it ordinarily was in other, similar fractures. In these instances of delayed union, however, solid bony union usually occurred eventually, and the end result was compatible with normal function.

At Halloran General Hospital, Maj. George K. Carpenter, MC, and his associates set up a third category of results, which they termed "limited union" and which they defined as healing of some degree but so limited that full function was not practical (*9*). The bone in question was always weaker, and usually smaller, than normal.

Limited union was most frequent in the femur and tibia, but occurred also in the humerus, radius, and ulna. It sometimes followed simple fractures, particularly fractures of the femur, when the fragments were displaced, but was most often observed after severely compounded and comminuted fractures with associated loss of substance. The primary injury might have been actual blowing out of the bone by a high velocity missile. Removal of bone fragments at debridement, whether or not they were attached to the periosteum, was another cause. Radical surgery of this extent was sometimes necessary, but at times was overzealous.

Limited union was manifested in several ways: By bridging callus, with no evidence of union between the fragments; by bridging of large bony defects by comminuted fragments that were obviously incapable of tolerating unprotected weight-bearing; and by loss of large comminuted

fragments, not including the whole circumference of the shaft, with resulting diminution in the size of the bone at the site of union. Refracture was another manifestation of limited union; in spite of the awareness of the problem at Halloran General Hospital and vigilance in guarding against the accident, two refractures occurred in cases of limited union over a 2-year period.

It was not always possible to determine when union had progressed as far as it was likely to go, but for practical purposes, limited union was said to be present if serial roentgenograms over a 2-month period showed no material increase in callus formation at the site of the defect. In these cases, the protected use of the extremity and the prolonged wearing of braces did not usually produce any visible improvement. In fact, extensive scar formation was almost always found at operation at the site of the defect, with very poor chances for new bone formation.

Case 1.—The first patient with limited union treated by bone grafting was received at Halloran General Hospital on 30 April 1943, a month after he had sustained a severely compounded, comminuted fracture of the upper third of the shaft of the right femur from a sniper's bullet in North Africa. He also had a compound fracture of the left radius.

He was removed immediately from the plaster applied after wounding and was put up in balanced suspension skeletal traction. The soft-tissue wound healed promptly.

Clinical and roentgenologic examinations 4 months after injury showed some bony union. There was, however, so much loss of substance at the fracture site that traction was continued for another 4 months. At the end of this period, there was no change in the roentgenographic findings, and a reinforcing bone graft operation was done on 30 November 1943. Wound healing was prompt and satisfactory and the patient was left with no shortening, no deformity, and entirely normal function. A well-supervised physical therapy program had preserved muscle tone and joint motion.

In retrospect, it was clear that this patient could readily have been operated on 3 months earlier, since wound healing was complete within 2 months after injury and infection was never a problem. This was the first case in which—after the event—the category of limited union was recognized. After this experience, a program for such cases was set up, which included prompt surgery, usually within 3 months after complete wound healing.[5] The usual preoperative and postoperative regimens were followed, and any standard technique of bone grafting was considered acceptable. It is not an exaggeration to say that, in practically every instance, the defect found at operation was greater than had been demonstrated roentgenologically or suspected clinically.

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[5] One must agree with the orthopedic surgeons at Halloran General Hospital that bone grafting would eventually be necessary in all such cases and there was small point to delaying it, once the usual criteria were met. The union achieved to date was insufficient and there was not enough solid bone substance present for the extremity to be functional. More bone was obviously needed before weight-bearing was possible. All orthopedic surgeons encountered cases of this kind, but most of them classified them as instances of delayed or partial union, in which bone continuity existed but strength for normal use was inadequate. Halloran General Hospital was not the only hospital in which valuable time was lost in the generally laudable attempt to be conservative.—M. C.

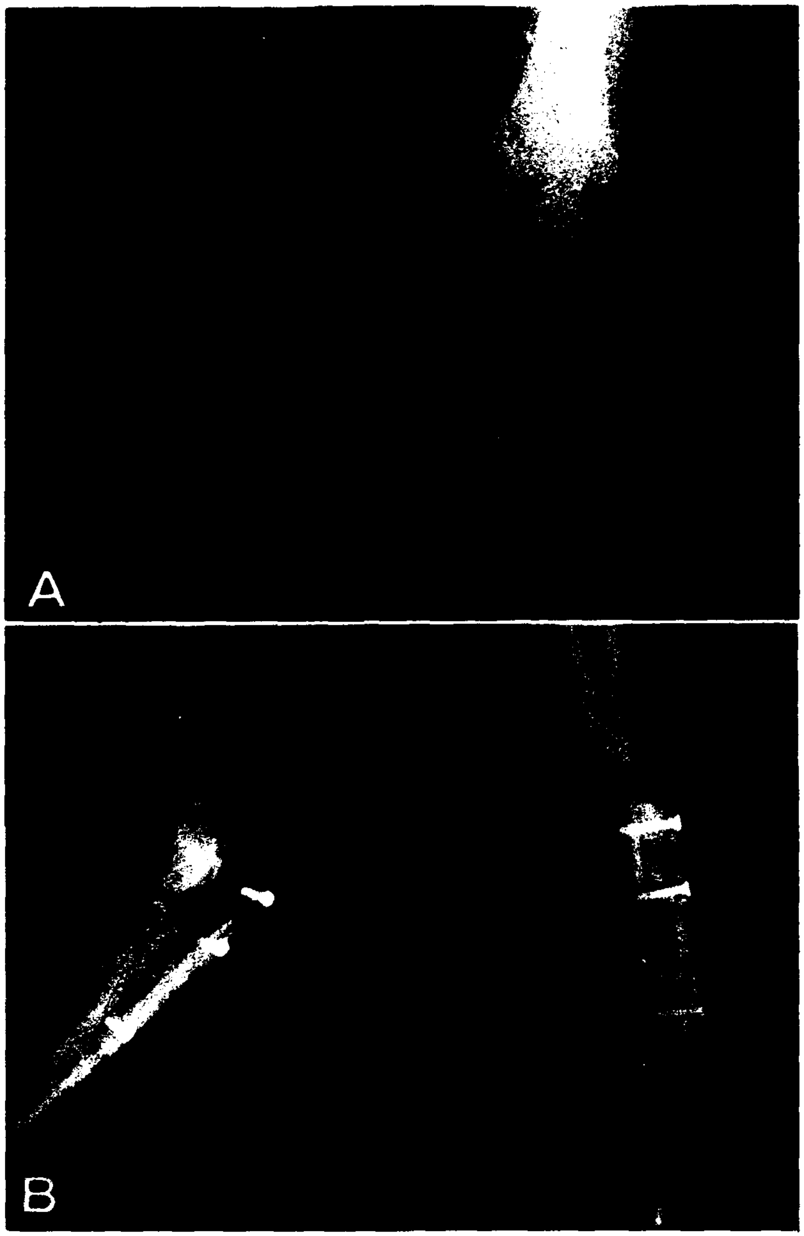

Figure 106.—Management of compound, extensively comminuted fracture of left elbow by bone grafting. A. Anteroposterior and lateral roentgenograms of elbow day after injury. Note extent of comminution. B. Lateral and anteroposterior roentgenograms 2 weeks after bone grafting. Note position of grafts and of fragments.

SPECIAL EXPERIENCES

Battey General Hospital.—At Battey General Hospital, bone grafting was performed by a combined intramedullary and onlay technique, with

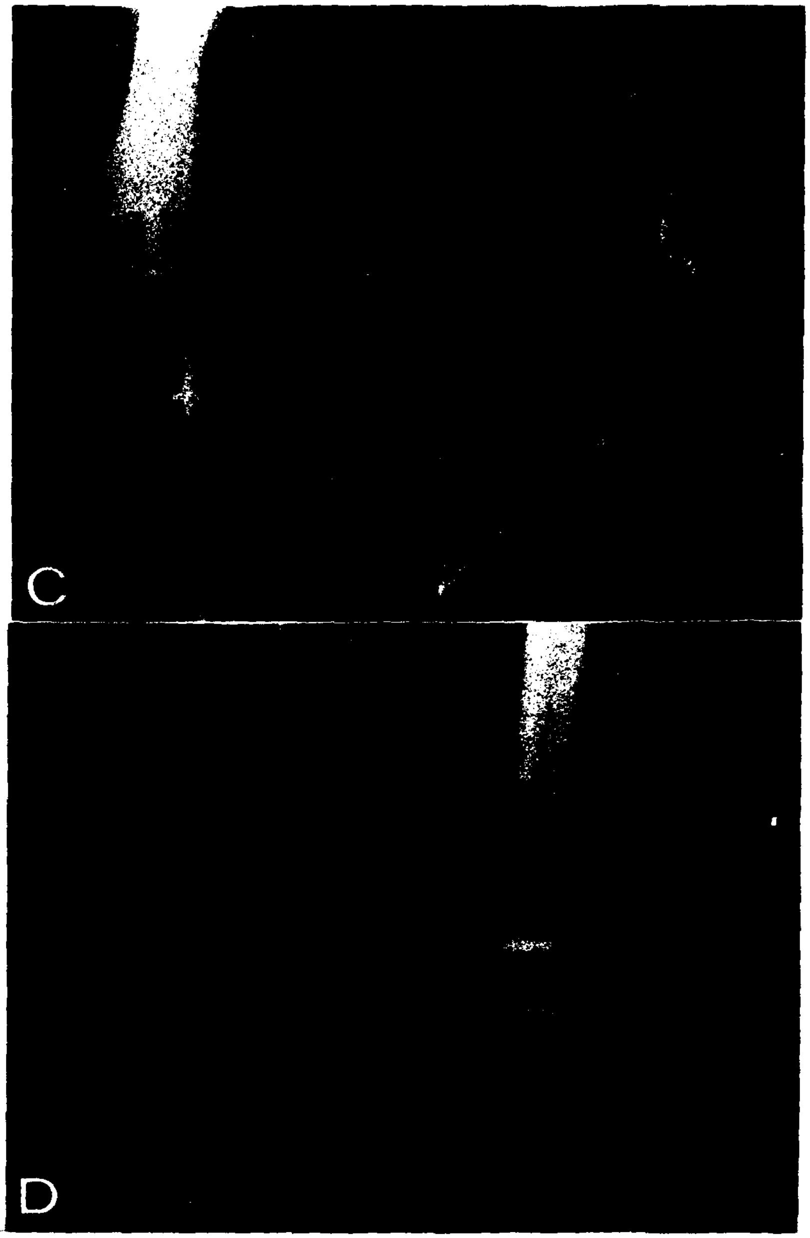

FIGURE 106.—Continued. C. Anteroposterior and lateral roentgenograms 8 weeks after operation. Note evidence of early bone repair. D. Lateral and anteroposterior roentgenograms 7 months after operation. Note complete incorporation of graft in bone and solid fusion of all bone fragments. (Bishop, W. A., Jr., Stauffer, R. C., and Swenson, A. L.: J. Bone & Joint Surg. 29: 961–970, 976, October 1947.)

grafts from the tibia, supplemented, when necessary, by chips from the ilium (*6*). This technique was used in 52 cases, 42 of which were followed up for a minimum of 4 months and a maximum of 7 months, with complete

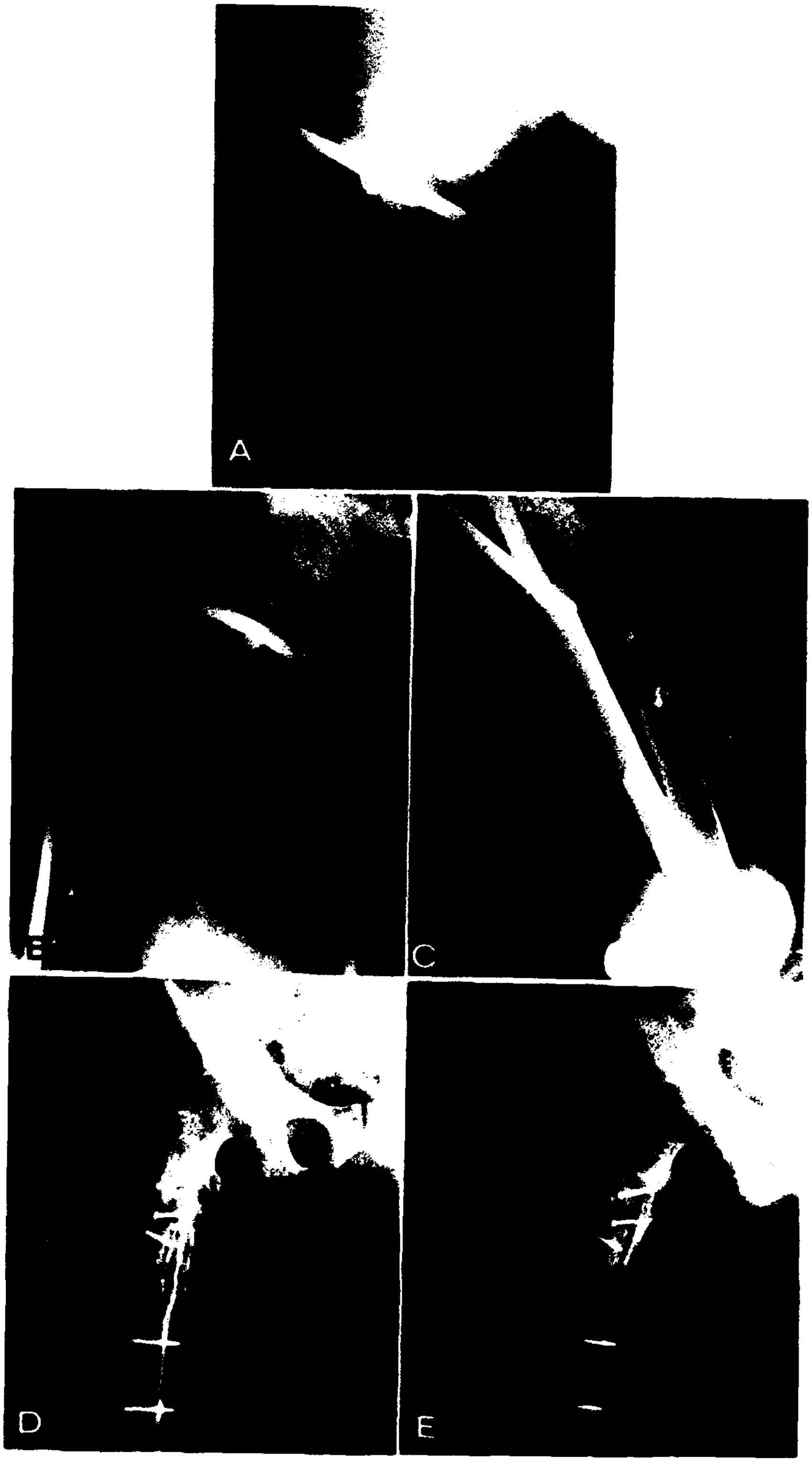

Figure 107.—*See opposite page for legend.*

roentgenographic studies. There were nine failures, chiefly the result of absorption of the graft. One of the three refractures was caused by too early manipulation.

William Beaumont General Hospital.—At Beaumont General Hospital, El Paso, Tex., only 30 bone grafts were performed in the 19-month period ending in December 1943, 19 for nonunion of compound fractures (*10*). During this period, sulfanilamide and sulfathiazole powder were used locally, and most patients received sulfadiazine systemically. Between January 1944, when penicillin first became available, and October 1945, 255 bone grafts were performed, 163 for un-united compound fractures. The original waiting period of 6 months after healing was gradually shortened to 3 months unless there was clinical or roentgenographic evidence, or both, of present or previous osteomyelitis or other infectious processes.

Causes for failure of healing in the 92 simple fractures in this series were inadequate early immobilization or reduction (28 cases), delayed internal fixation (26 cases), internal fixation without adequate reduction (14 cases), overtraction with separation of fragments (10 cases), distraction by the Roger-Anderson apparatus (eight cases), and unknown causes (six cases).

The causes for failure in 193 compound fractures included loss of substance (54 cases), infection (30 cases), inadequate early immobilization and internal fixation without adequate reduction (14 cases each), overtraction (10 cases), inadequate reduction and separation of fragments by the Roger-Anderson apparatus (eight cases each), and undetermined causes (25 cases).

Chronic edema, usually rather severe, was present in an estimated 65 percent of the cases of nonunion. The effect of chronic passive hyperemia on bone healing was not clarified during the war, but it was considered a deciding factor in a large number of instances.

At this hospital, transfer inlay and Albee grafts were used in the early experience, but results were not entirely satisfactory. Dual onlay grafts came into use in the last 6 months of 1943 and steadily increased in popularity thereafter. Originally, they were used only in bone defects or in fractures near joints. Later, they were used in all cases in which the early experience had shown that massive onlay grafts were likely to fail or to require undue prolongation of healing time. The average adult tibia could

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FIGURE 107.—Management of compound comminuted fracture of right femur by bone grafting. A. Anteroposterior roentgenogram of femur in traction 5 months after injury. Note comminution at fracture site and bone defect. B and C. Anteroposterior and lateral roentgenograms 16 days after operation. Note position of dual graft. The fibular graft on the medial aspect extends well into the neck of the femur and the tibial graft on the lateral aspect extends into the greater trochanter. The defect is well filled with a graft from the fibula and bone chips. D and E. Anteroposterior and lateral roentgenograms 4½ months after operation. Note healing of grafts. A brace was fitted at this time. (Bishop, W. A., Jr., Stauffer, R. C., and Swenson, A. L.: J. Bone & Joint Surg. 29: 961–970, 976, October 1947.)

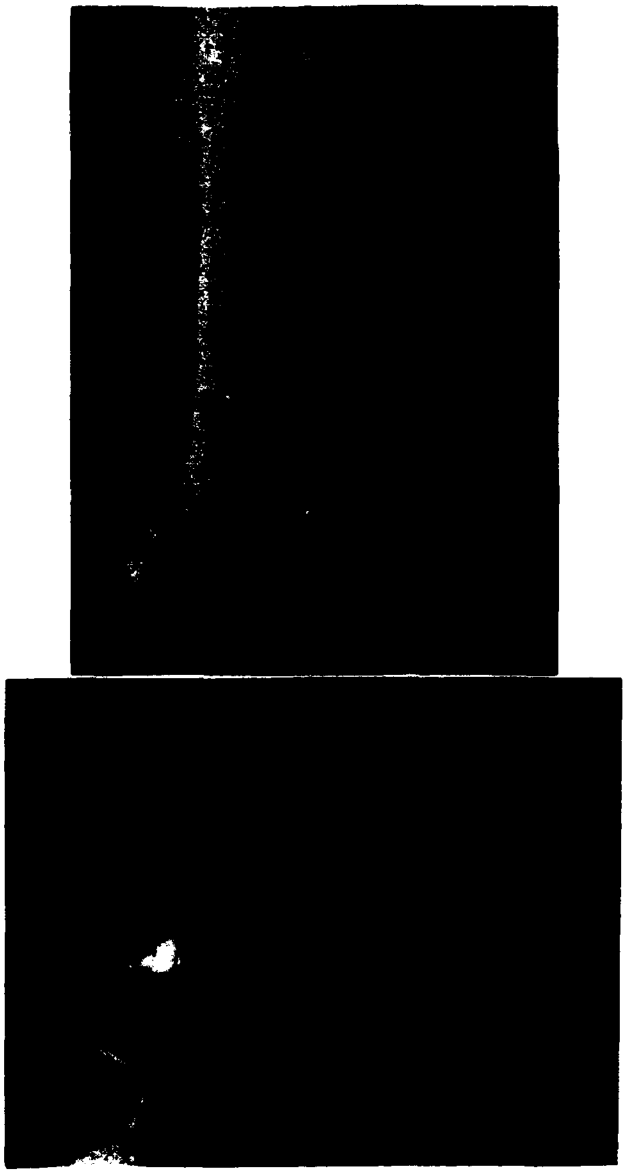

FIGURE 108.—Management of compound comminuted fracture of right humerus by bone grafting. (Top) Anteroposterior and lateral roentgenograms 6½ months after injury. Note proximity of fracture to humeral condyles. (Bottom) Same, 3 months after operation. Note extension of grafts into condyles of humerus. They are not yet well incorporated, but the fracture appears to have healed. (Bishop, W. A., Jr., Stauffer, R. C., and Swenson, A. L.: J. Bone & Joint Surg. 29: 961–970, 976, October 1947.)

provide a graft 11.5 inches long. Onlay and inlay grafts were, however, used in the majority of cases. Peg grafts were not used very often. In evaluating dual onlay procedures, it had to be borne in mind that this

technique was used only when it was thought that it would be unusually difficult to secure union by other methods. In such cases, the time saved in healing justified the additional surgery necessary when the dual onlay technique was used.

The criterion of healing was roentgenologic evidence of union of the fracture fragments and of the graft (figs. 106–108). The average healing time for massive onlay grafts was 19.9 weeks; for dual onlay grafts 16.8 weeks; and for inlay grafts 19.9 weeks (32.3 weeks when metacarpal grafts were excluded).

There were five refractures in the 78 inlay grafts, at an average of 13 weeks after operation. The three fractures in the 104 onlay grafts occurred at an average of 9 weeks. All eight patients were in traction for fractures of the femur, and their lack of cooperation was the chief reason for the refracture. In four of the eight cases, a second graft was inserted without delay and healing was prompt and satisfactory. The experience in the other four cases, in which delay was practiced and in three of which the period of healing averaged 48 weeks, was clear evidence of the value of prompt regrafting after refracture.

U.S. Army General Hospital, Camp Edwards, Mass.—In the 8-month period ending with December 1945, 102 bone grafts were performed on 100 patients at this hospital, 80 of them by a single surgeon, Maj. Byron B. King, MC (*11*). There were 91 compound fractures.

The following techniques were used:

Cases	*Techniques*
43	Tibial onlay
2	Tibial onlay plus iliac bone
2	Tibial onlay—intramedullary
6	Tibial inlay
2	Sliding tibial inlay
8	Tibial recess
1	Tibial recess plus iliac bone
1	Tibial intramedullary plus iliac bone
5	Sliding tibial inlay plus plate
2	Dual, tibial onlay
2	Dual, tibial onlay and iliac inlay
1	Dual, tibial onlay and tibial recess
1	Dual, tibial recess and tibial intramedullary
1	Dual, tibial onlay and iliac onlay
2	Dual, tibial onlay and tibial inlay
2	Dual, tibial onlay and sliding tibial inlay
1	Dual, tibial inlay with plate and tibial onlay
1	Dual, tibial intramedullary plus Smith-Petersen nail
3	Iliac recess
1	Iliac recess plus plate
1	Iliac onlay
12	Plate plus iliac bone
1	Plate plus tibial bone
1	Proximal fibula (for distal ulnar loss)

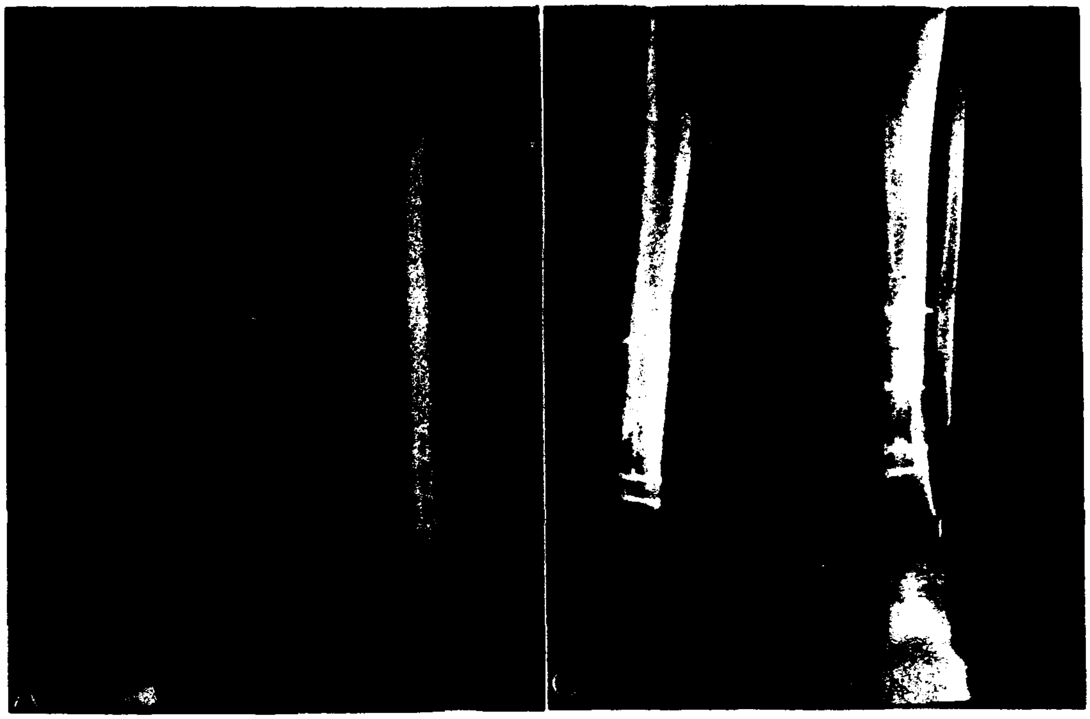

FIGURE 109.—Management by bone grafts of compound fractures of lower third of left tibia and fibula sustained by rifle fire, 22 January 1945. A and B. Preoperative anteroposterior and lateral roentgenograms showing union that is indeed "frail" if not actually nonunion, as well as poor alinement of fragments. C and D. Lateral and anteroposterior roentgenograms, 7 September 1945, almost 3 months after curved osteotomy and application of recessed graft from right tibia, fixed by four screws. The malposition has been corrected and union of the fracture is progressing well. (King, B. B.: Am. J. Surg. 74: 129–135, August 1947.)

Indications for bone grafting consisted of nonunion (54 cases), bone defects (16 cases), "frail" union (fig. 109) and malunion (15 cases), "frail" union and shattered joint (seven cases each), and a bone cavity in the remaining case. Timing was individualized, the range being from 6 weeks to 13 months and averaging 3 ½ months. One or more saucerizations and sequestrectomies were often necessary before healing occurred and definitive surgery could be considered.

Postoperative complications occurred in 40 cases, as follows:

1. Infection in 21 cases, 15 of which were minor. One patient with a major infection, however, eventually required below-knee amputation, an operation that it might have been wiser to perform originally because of the seriousness of the tibial injury and of the subsequent osteomyelitis. The remaining infections, all extensive and persistent, occurred in serious tibial (three) and femoral (two) injuries.

2. Fracture of the graft in eight cases, of the donor tibia in five cases, and of the femur in one case. The femoral fracture occurred when the physical therapist attempted to increase motion in the knee. Two of the fractures of the donor tibia occurred at operation, when the graft was removed. All fractures of the graft were in massive tibial

onlays; six were in the femur, one in the humerus, and one in the ulna. A number of these fractures were the result of fresh trauma. Displacement occurred in only three cases.

3. Slipping of the grafts, with loss of position in three cases, all in femurs with massive tibial onlay grafts, and all while the patients were in traction-suspension.

4. Transient tourniquet paralysis in two cases.

Mayo General Hospital.—At this hospital, located at Galesburg, Ill., 82 bone grafts were carried out in 65 patients between February and September 1945 (*12*). Included were 70 compound fractures, 64 of which were secondary to combat-incurred wounds, and 66 of which were considered infected.

In 55 of these cases, it was possible to estimate when drainage had ceased. The period was between 8 and 10 weeks before operation in 19 cases, in which four infections occurred and one graft was lost; between 3 and 4 months in 22 cases, in which five infections occurred and three grafts were lost; and between 4 and 19 months in 14 cases, in which three infections occurred and no grafts were lost.

Of the 82 grafts applied, 69 were tibial, eight iliac, and three both tibial and iliac. In one case, a 7-inch long fibular graft was used to replace an ulna, and in another, the distal 1½ inches of ulna were resected and used as a radial graft. Two staged operations were done in the series, one for a humeral and the other for a radial lesion. An open reduction was done on a long, oblique, un-united fracture of the humerus. In the remaining case, in which the entire radial shaft was missing except for 1½ inches of the distal end, the distal end of the adjacent ulna was placed into the medullary canal of the short radial fragment, a procedure which gave the patient a one-bone forearm.

Combined bone grafting and nerve repair were carried out in 16 cases, 15 of which were considered highly promising when the report was made. This type of surgery (figs. 110 and 111) is discussed in detail in another volume of this historical series (*13*).

Complications were as follows:

1. Infection in 12 cases, in seven of which the bone was involved and drainage was required.

2. Fractures of the grafts or the grafted bones in nine cases. Four of the fractures occurred while the patients were in plaster and the others after trauma. None involved tibial grafts.

3. Vascular complications in two cases.

There were no failures in the noninfected group, which consisted of five simple and four compound fractures. In the 73 infected cases, there were 15 initial failures, of which five were caused by infection, nine by fracture of the graft or the grafted bone, and one by thrombosis of the popliteal artery. Amputation was required 3 days after operation in the last case mentioned. Trauma apparently was sustained by the stretch put on the artery in alinement of the fragments; if grafting had been done while the fragments were displaced, this complication would probably not have occurred. In at least two of the nine refractures, technical errors were considered responsible for the failures.

Fitzsimons General Hospital.—The distinctive feature of the bone grafting technique used at Fitzsimons General Hospital (Denver, Colo.) by Lt. Col. Vernon L. Hart, MC, and Capt. A. Jackson Day, MC (*14*), was bridging of the defect with (1) a long cortical inlay graft from the opposite

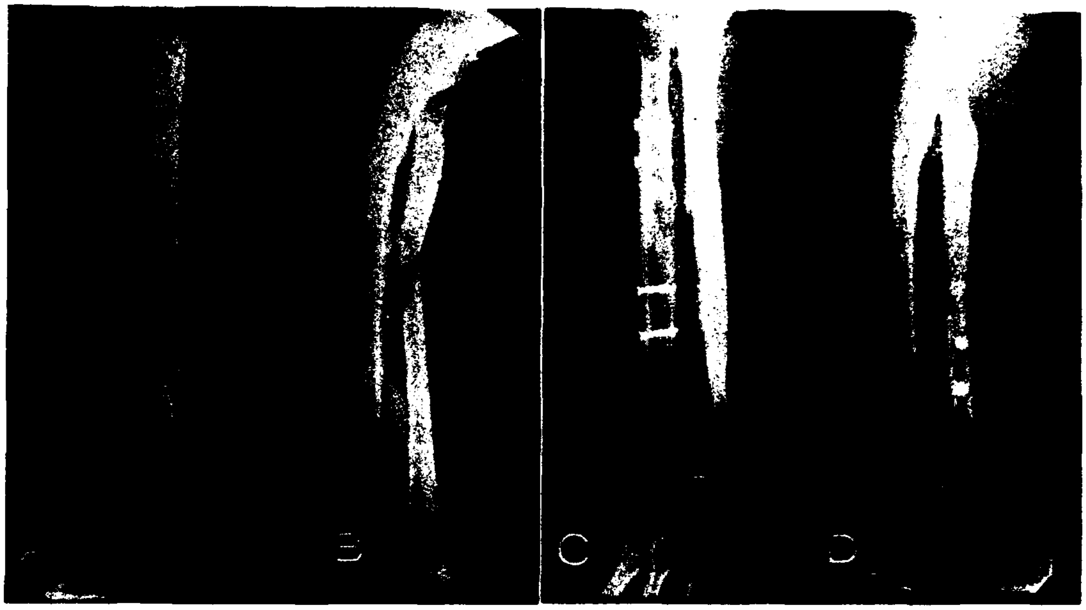

FIGURE 110.—Management of un-united fracture of shaft of right radius caused by bomb fragment, 17 July 1944. Nonunion was associated with paralysis of the radial and median nerves, which was treated by neurorrhaphy. A and B. Anteroposterior and lateral roentgenograms, 7 December 1944, showing nonunion of the radial fracture. The ulnar fracture is united. C and D. Anteroposterior and lateral roentgenograms 8 months after neurosurgical repair and fixation of tibial bone graft to radius by four screws. The radial fracture is now firmly united. (Farrington, J. D.: The Treatment of Non-Union and Correction of Large Bone Deficits. [Unpublished data.])

tibia, which was stabilized by proximal and distal screws, and (2) two shorter onlay grafts from the ilium, which were fixed by stainless steel screws and in which cancellous bone was predominant.

Fletcher General Hospital.—At this hospital, located at Cambridge, Ohio, Colonel Rizzo and Captain Lehmann cut their bone grafts 3–4 centimeters longer than the trough which they were intended to fill and wedged them into the medullary cavities of the distal and proximal fragments. The grafts thus acted as intramedullary grafts, since both prolongations were well engaged in the medullary canals of each fragment. After 6 months, as already mentioned (p. 406), the outlines of the grafts were barely discernible.

This technique was used with satisfaction in nonunions of the femur, humerus, radius, ulna, and metacarpals.

Vaughan General Hospital.—At this hospital, located at Hines, Ill., Lt. Col. Thomas Horwitz, MC, and Lt. (later Capt.) Richard G. Lambert, MC, utilized a full thickness iliac onlay graft, combined with iliac strips used as inlay grafts, in the medullary cavity (*15*). The onlay full thickness graft was fixed to the distal and proximal fragments by screws. Additional fixation was provided by a metal plate held by screws to each bone fragment.

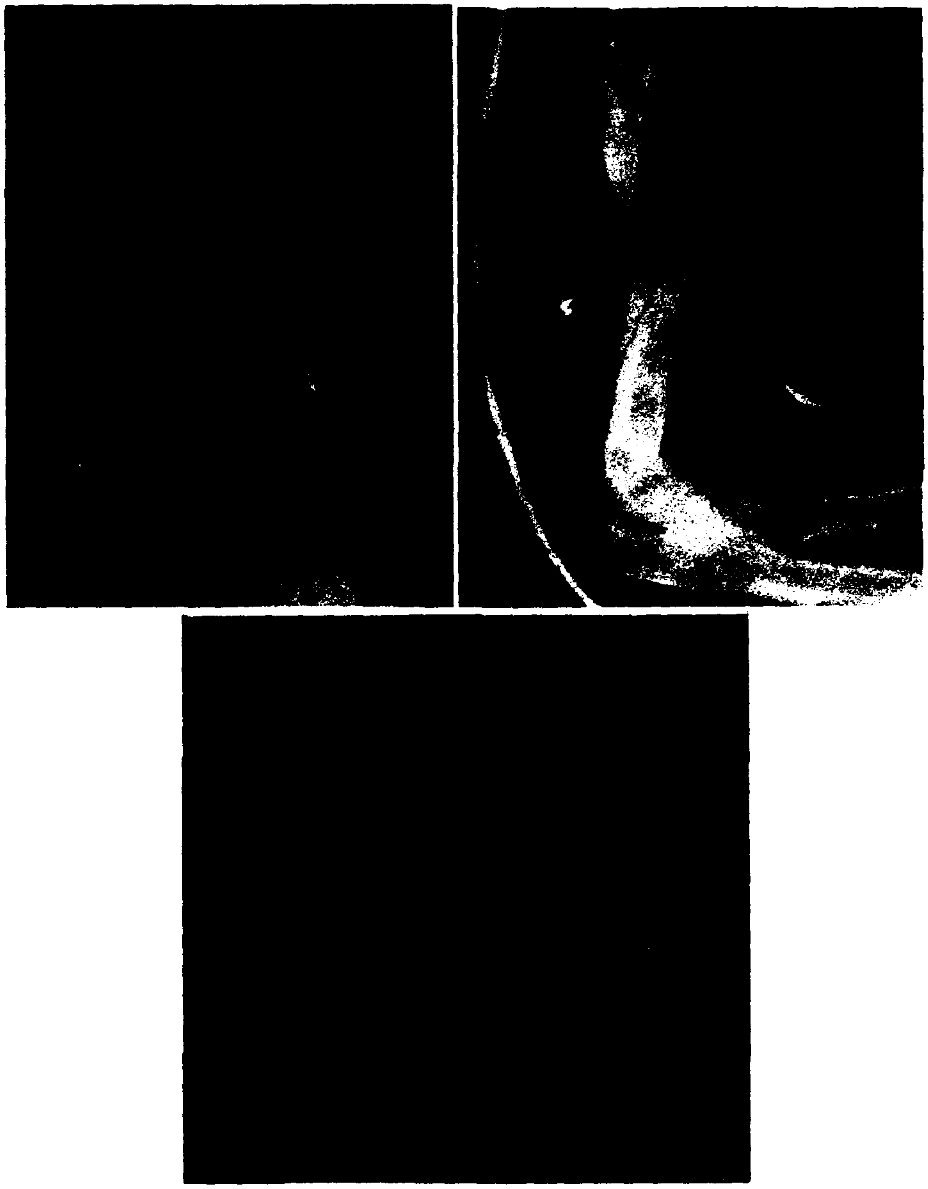

FIGURE 111.—Management of gunshot wound of arm by bone grafting. The fracture of the humerus was complicated by paralysis of the radial, median, and ulnar nerves. Ligation of the brachial artery was necessary. (Top) Anteroposterior and lateral roentgenograms 2 months after injury showing nonunion of fracture with many loose fragments. (Bottom) Same, 8 months after application of dual tibial bone grafts fixed by screws. Note sound healing. Neurorrhaphy of the radial and median nerves and neurolysis of the ulnar nerve were performed when internal fixation was done. (Farrington, J. D.: The Treatment of Non-Union and Correction of Large Bone Deficits. [Unpublished data.])

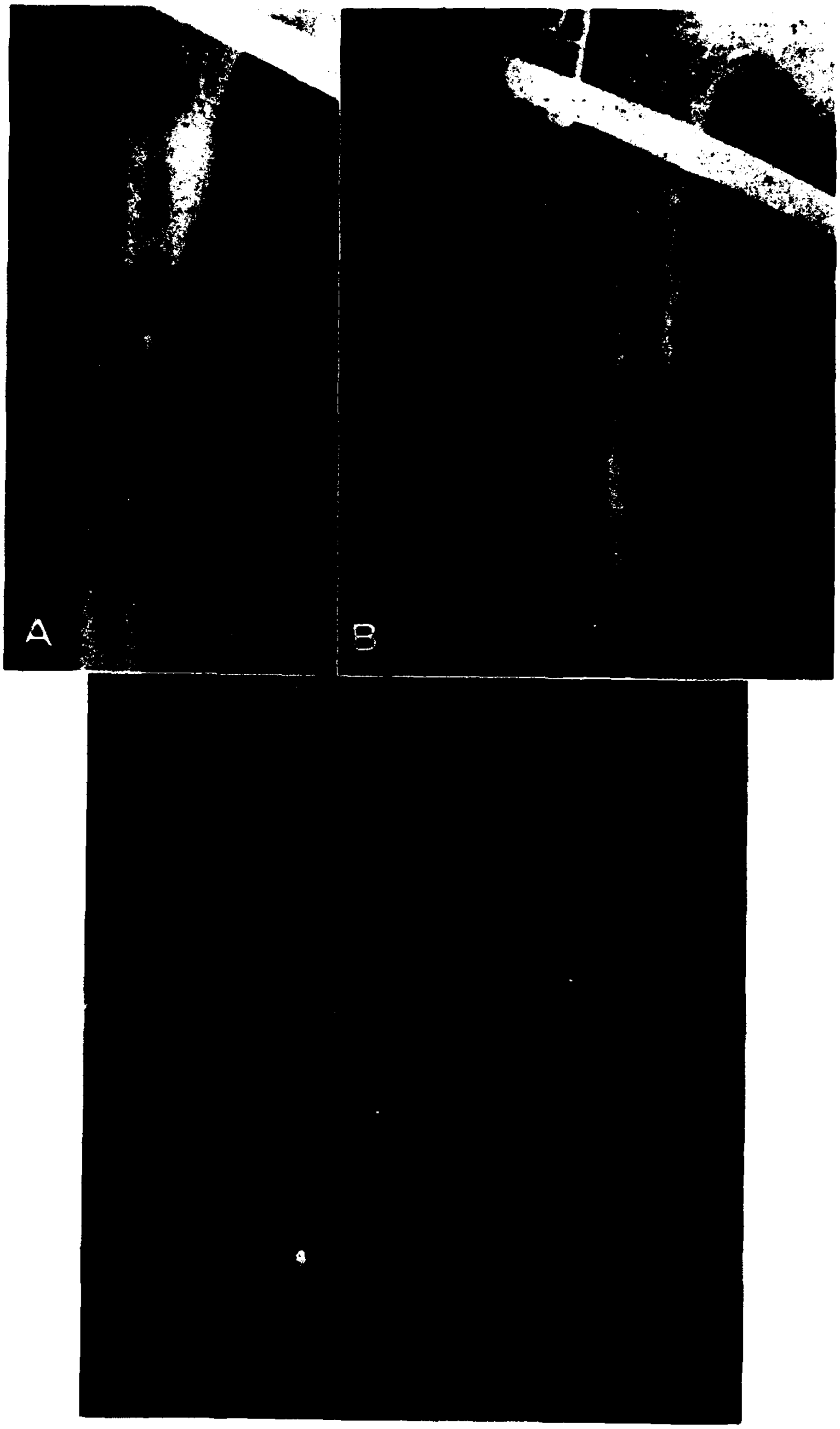

FIGURE 112.—*See opposite page for legend.*

Of the 16 operations performed by this technique, 10 were on the femur (fig. 112), four on both bones of the forearm, and two on the tibia.

In five of the 10 femoral fractures, solid union had been attained at the time of the report and the patients had been ambulatory, in ischial weight-bearing calipers, 16 weeks after operation. The group included a patient who had a nonunion of the opposite tibia, which was also grafted with ilium. The five fractures not yet ready for evaluation because of the brief period after operation all showed the same rapid progress toward union and incorporation of the grafts. Results were equally satisfactory in the four bones of the forearm and in one of the two fractures of the tibia; the other was not ready for evaluation. The only complication in the series was nonorthopedic, a recurrent attack of malaria. Many orthopedic injuries were complicated by this and other tropical diseases, chiefly in casualties from the Pacific.

FIBULAR GRAFTS

A report by Capt. Richard C. Miller, MC, and Maj. George S. Phalen, MC, from O'Reilly General Hospital, Springfield, Mo., was limited to the repair of 16 defects of the radius by grafts from the fibula (*16*).

The fibula graft, preferably taken from the leg opposite the injured arm, was at least 3 inches longer than the defect in the radius. At least 3 inches of the distal fibula was left in situ, to maintain stability of the ankle mortise. The distal end of the ulna was excised to allow reduction or alinement of the distal fragment of the radius. The radial fragments were trimmed back to healthy bone. Half the thickness of the fibula graft was sawed from each end. The remaining central full-thickness portion was the exact length of the defect to be bridged. The graft was then mortised snugly into the distal and proximal radial fragments, the half-thickness detached ends of the graft being used as onlay grafts. The principal fibular graft was fastened to the proximal and distal fragments at each end by two Vitallium screws.

The nonunions of the radius selected for this technique had the following characteristics:

1. Prominence of the distal end of the ulna and marked radial deviation of the hand because of the relative overlength of the ulna, which resulted from shortening of the radius.
2. Loss of active pronation and supination of the hand, typically seen when the loss of bone in the radial shaft was distal to the insertion of the pronator teres.
3. Frequent loss of extensor power in the fingers and thumb, sometimes caused by severance of the deep branch of the radial nerve and sometimes by avulsion of muscular substance.

FIGURE 112.—Management of simple fracture of upper third of shaft of right femur by bone grafting. A. Anteroposterior roentgenogram 5½ months after injury. The interpretation (open to question) was that there was good callus formation and firm bony union. B. Same, 7 days later, after refracture while patient, wearing walking caliper brace, was getting into bed. Note definitive displacement at fracture site. C and D. Anteroposterior and lateral roentgenograms 16 weeks after application of iliac bone graft and fixation with metal plate and screws. Abundant callus is evident, and lateral view suggests solid bony union. (Horwitz, T., and Lambert, R. G.: Surg. Gynec. & Obst. 82: 573–578, May 1946.)

Fracture did not occur in any of the 16 grafts in this series, but was observed in two other cases in which a fibular graft was employed in defects of the ulna. The circumstances emphasized the importance of extremely accurate contact between graft and fragments, as well as immobilization for at least 14 to 18 weeks, with protection of the forearm for another 8 to 12 weeks.

The orthopedic surgeons who devised the fibular graft technique considered that the chief factors in their success were the measures taken to prevent infection, including delayed surgery, careful skin preparation, careful attention to technical details, and antibiotic therapy before and after operation.

STRIP GRAFTS FROM THE ILIUM

The report by Capt. Frederic W. Rhinelander, MC, from Hammond General Hospital, Modesto, Calif., is abstracted at considerable length for two reasons: It concerns a large series of bone defects (104), and it was a precisely planned study (*17*).

Materials and Methods

The 104 operations on 102 patients in this series were performed between 1 May 1945 and 1 November 1945. With a single exception, a patient received from DeWitt General Hospital, Auburn, Calif., all operations were performed by members of the Hammond General Hospital staff. Infection was present in 36 cases.

The objective of the study was to test further the use of iliac bone for bone grafts, as demonstrated by Abbott and his associates (*8*) and by Mowlem (*18*). Their earlier experimental observations were borne out, that even in infected bony cavities, a large proportion of grafted iliac bone survives and solid healing is ultimately obtained. Cancellous bone chips from which all cortex had been removed were most efficacious.

Bone was usually secured from the anterior and posterior portions of the crest of the ilium, which, Abbott's studies had shown, contain the greatest amount of cancellous substance. The anterior iliac crest was the usual donor site in clean cases. Slices of cortical and cancellous bone were cut from the crest and split longitudinally into thin strips. In infected cases, the posterior ilium, which is thicker, proved the better source. The graft was removed in the form of blocks, which were cut into appropriate sizes.

When strip grafts were used (fig. 113), care was taken to slot the ends of the fracture fragments opposite each other well back into normal bone. This step served to carry the thin iliac grafts across the defect, whether or not internal fixation was also employed. The same type of slots was employed when massive onlay grafts were used. If the defect was only

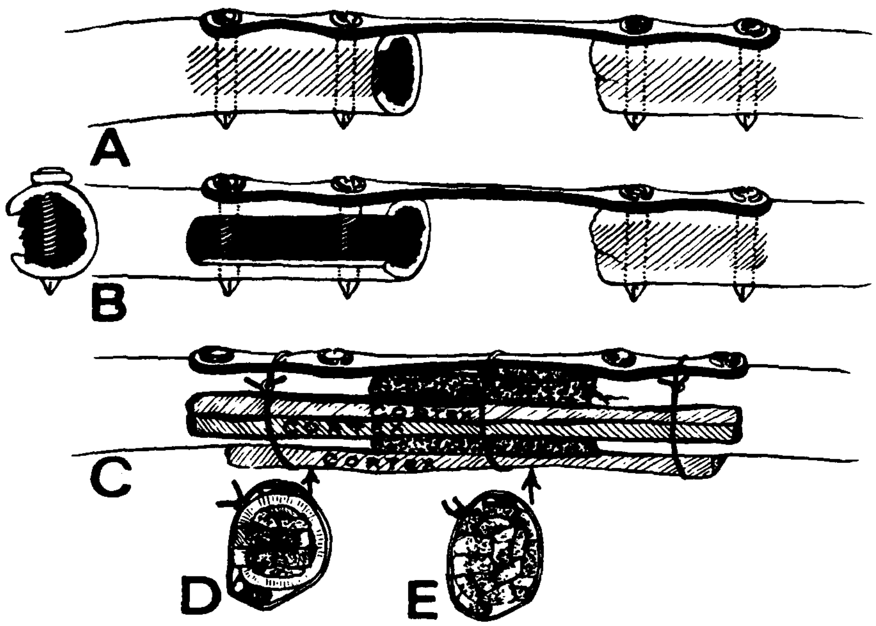

FIGURE 113.—Technique of repair of bone defects by cortical cancellous strip grafts. These illustrations depict repair by this technique combined with application of a Lane plate. The same technique is used when a tibial onlay graft is applied or when reinforcement is omitted. A. A plate of suitable length is screwed firmly into place across the defect. B. The bone ends are slotted along one side, away from the screws (see cross-section). C. Strip grafts are placed in the slots to bridge the defect (in a larger bone, more key grafts would be used). The remainder of the defect is filled with shorter cortical cancellous grafts or with cancellous strip grafts only. Long grafts may also be placed on the external surface of the bone. The grafts are bound together by circumferential catgut. D and E. Cross-sectional diagrams at points illustrated by arrows. (Rhinelander, F. W.: The Use of Iliac Bone Graft in Bone Defects. [Unpublished data.])

partial, the slots were so placed as not to weaken whatever bridge of union might be present. If the iliac strip grafts were not long enough to reach from the basal end of one slot to that of the other, they were placed deeply in each slot and overlapped in the intervening space. After these key grafts were positioned, other strip grafts were placed as compactly as was possible without pressure to fill in the remainder of the defect. A few long, thin strips were sometimes placed around the external surface, overlapping each bone. It was also helpful to bind all strip grafts together with circumferential loops of catgut, the bundle thus produced resembling a bunch of faggots.

Spinal anesthesia was preferred whenever it could be used. It facilitated turning the patient between the steps of the operation, and also obviated the need for an intratracheal tube while he was lying on his face.

Analysis of Results in Clean Fractures

The distribution of procedures and the results obtained in the 68 clean cases treated by iliac grafts were as follows:

1. Strip grafts were used to fill partial defects of the bone in 15 cases and to bridge complete defects in 12. All but one of the injuries was a gunshot wound.

Primary healing of the surgical wound occurred in all but three cases. In the first, drainage ceased spontaneously after 5 weeks and normal healing followed. In the second, a plastic skin flap became partially necrosed, but without deep drainage. In the third, a large defect in the upper tibia had been lined with split thickness skin at another hospital. When the iliac grafts were inserted, a flap of skin was rotated to cover the surface of the wound; the tip of the flap went on to necrosis, without, however, drainage from the region of the grafts.

Refracture of a partially united femur occurred in one patient in traction, without loss of position, the day after operation. Loss of alinement occurred in one case at 3 months. In one case, nonunion persisted in a tibia, perhaps because the technique of slotting the bone ends for receipt of the iliac grafts had not been employed.

2. Iliac cortical-cancellous strip grafts plus massive bone grafts were employed to bridge complete defects of the bone in 16 cases, to repair a depressed tibial plateau in one case, to arthrodese the posterior facet of a subastragalar joint in one case, and to arthrodese a wrist in three cases.

Primary healing of the surgical wound occurred in this group in all but three old compound fractures of the tibia, in all of which timing of the operation was poor. In two of these failures, a plastic procedure should have been carried out to replace widely cicatrized skin before the grafts were inserted. In the third case, operation was performed while a small area of superficial granulation was still present.

In one case, the tibia from which a graft had been taken 4 months earlier fractured when the patient vaulted a low gate.

Nonunion occurred in one case in which poor surgical judgment was exercised: Both bones of the forearm were reconstructed at operation. A massive iliac onlay graft was used for the radial defect and a Lane plate for the ulnar defect, with strip iliac grafts. Relaxing incisions had to be made before the skin incision was closed, and even then, there was tension in the deeply scarred soft tissues. The ulnar wound broke down, and to apply wet dressings to it, the forearm frequently had to be removed from plaster. Nonunion followed. Excision of scar tissue a month or more before bone grafting, combined with a skin graft to relax the soft tissues, might have changed the outcome in this case.

3. Iliac cortical-cancellous strip grafts, supplemented by metallic internal fixation, were used in 20 cases, in 16 of which the upper extremity was involved. A Lane plate was used in 17 of these cases and was found

particularly useful in the forearm, as the larger surgical procedure of taking a graft from the tibia was thus avoided.

Infection developed in three of the 11 operations on the forearm. In two instances, the reason was clear, closure of the wound under tension at operation because plastic skin grafting had not been carried out before bone surgery. In the third case, the origin of a small sinus about 3 centimeters lateral to the well-healed main wound had not been determined when the patient was transferred to another general hospital. In another operation on the forearm, in which healing had been per primam, an area of bone absorption appeared about the distal screw, associated with a narnow zone of nonunion between the distal fragment and the mass of iliac bone grafts. When the plate was removed 6 months after operation, no exudate was found, but culture revealed *Staphylococcus* and an unidentifiable gram-negative *coccobacillus* which was found in many patients from the Southwest Pacific Area. It was presumed that these organisms were in situ before the grafting operation. This was an early operation, in which the bone ends were not slotted and only short chip grafts were used. Gross infection required early removal of the plate in another operation performed by this technique.

Infection developed in two of the five operations on the humerus in which strip grafts were used with metallic internal fixation. In one of the cases, the plate was not fixed adequately and became loose shortly after operation. In the other, spontaneous healing occurred under closed plaster treatment after drainage had continued for 5 weeks. The fracture united well during the 3 months the patient was under observation, but roentgenograms at this time showed slight absorption about two of the screws and it was realized that the plate eventually would require removal.

In the single case in which this technique was used to repair a tibial defect, a low-grade infection developed, again because skin grafting was not performed before the bone operation. The wound had to be closed under tension, the central portion did not hold, and the plate and most of the grafts eventually had to be removed. Spicules of tibial cortex, which had been left devoid of periosteum, were found sequestrated in the depths of the wound.

Adequate drainage was essential in all infected wounds until full organization of the clot had taken place. The objective, to stabilize the clot and encourage the vascularization of as many grafts as possible, was defeated if blood or serum was allowed to back up in the depths of the cavity. Counterdrainage, used in a few cases not included in this series, seemed a promising technique.

When the cast was removed and the wound dressed 2 weeks after operation, most cancellous chips were found incorporated in organizing blood clot. Grafts completely loose in the central portion of the wound were picked out. Nonvascularized portions which projected from granulating tissue were cut off. The residual cavity was repacked with petrolatum-impregnated

gauze and a new cast was applied, for another 2 weeks. At subsequent dressings, any central grafts found necrotic were removed. After 6 weeks, if all nonviable chips had been removed at each dressing, the wound was usually found to have stabilized itself and the grafts in situ to have become incorporated in firm granulations.

Experience showed that frequent dressings to observe progress were unnecessary. When the technique just described was adhered to, over 75 percent of all cancellous iliac grafts inserted into infected bone defects remained viable and became incorporated in the healing bone. In infected cases, in fact, complete incorporation of the grafts in clean granulation tissue usually took place several weeks before the soft-tissue wound was completely epithelialized. All but one of the 10 gunshot wounds in the ends of long bones in this series were in the lower extremity, and in the case which healed most rapidly, a split-thickness skin graft was applied to the surface of the granulations as soon as the iliac grafts were fully covered. The bone defect in this case was the size of a walnut, much smaller than in the average case.

Partial Defects in Shafts of Long Bones

In 11 of the 12 operations for partial defects of the long bones, the injuries were combat-incurred. The defects measured 2 by 3 by 3 centimeters at the minimum and many were much larger. All the injuries in which healing took more than 4 months had been operated on before the closed plaster technique of postoperative management just described had been adopted. Up to 50 percent of the iliac grafts were lost in these cases, and the wounds were slow to granulate in.

In the twelfth case in this group, nonunion of a simple fracture of the tibia had been treated 7 months earlier, with a tibial onlay graft. Although union had occurred, a low-grade infection persisted. The wound was debrided, a portion of the old tibial graft was removed, and a moderate-sized cavity in the damaged tibia was cleaned out and filled with cancellous iliac chips. Healing was complete within a month.

Iliac grafts were used for three gunshot wounds of the tibia, all with complete defects. One of these cases was the only instance in the whole series in which debridement and insertion of the grafts were carried out at the same operation.[6] A moderate number of chips were lost, but consolidation was sufficient for weight-bearing with a brace within 3½ months.

[6] Aside from the surgical necessity for its performance, debridement preliminary to bone grafting had two advantages: (1) It revealed the true size of the bone defect, which was generally larger than roentgenologic examination had suggested, and it permitted an estimate of the amount of iliac bone that would be required to fill it. (2) Excessive hemorrhage from raw, freshly curetted surfaces was not present when bone grafting was done later, and the clot in which the grafts became embedded was, therefore, more rapidly stabilized.

Iliac Grafts of Bones of the Feet

Ten of the eleven partial defects of bones of the feet in this series were combat-incurred; the other was an old, infected open reduction. Eight of the wounds involved the os calcis, and one patient in the group also had a wound of the head of the first metatarsal. The other two patients had wounds of the midtarsal bones.

The os calcis is a notoriously difficult bone from which to eradicate deep infection. Four of the eight grafts were fully healed within 4 months after operation, and in two of the other cases, the iliac chips were fully incorporated in granulations within 6 weeks, but thereafter, epithelization was very slow. The two remaining patients each required a second crop of grafts. In one of these cases, grafts that were partly cortical had been inserted inadvertently. In the other, the central grafts had become necrotic and had to be removed. This was the only instance in which iliac cancellous grafts within the contours of the os calcis did not take fully in the presence of infection.

Iliac Grafts in Old Compound Fractures

Although old compound fractures have been discussed in connection with the techniques used to handle them, it seems justified to discuss them briefly from their standpoint alone (figs. 114 and 115):

In the 27 cases in which cortical cancellous strip grafts were used alone in such fractures, there was no instance of persistent infection. In three cases, primary healing did not occur. In one case, drainage ceased spontaneously after 5 weeks and the bone healed normally. In the other two cases, only the tips of the plastic skin flaps became necrotic. There were no instances of delayed drainage during the period of observation.

Nonunion persisted in one case, in which chips had been employed rather than long iliac grafts in a slot across the fracture site. When the chip technique was used in bones of the forearm, it gave, after 3 months, good stability in complete nonunion; in one case, an unusually long defect was bridged. In weight-bearing bones, consolidation took a much longer time. In the humerus, it occurred rapidly, but in complete fractures of the femur, it could not be expected under 6 months.

There were three instances of postoperative infection in 19 old compound fractures in which iliac strips or chips were used with metallic fixation, all instances of poor surgical judgment in respect to timing.

Fracture through a tibial donor site occurred in one case 4 months after removal of the graft, and there was one instance of persistent nonunion in which an iliac onlay graft was used with inadequate external fixation.

Massive iliac grafts proved especially useful as struts when postoperative strain could be minimized until consolidation had occurred. When these grafts were used as onlays, they had to be bulky in order to have strength, and they were difficult to fasten firmly in place when a defect in a long bone was being bridged. Tibial onlay grafts plus iliac strips constituted the strongest possible union, as in bridging a large defect in a femoral graft. Procurement of a graft from the tibia, however, added to the magnitude of the operation and required a second team of surgeons if the procedure was not to be unduly prolonged.

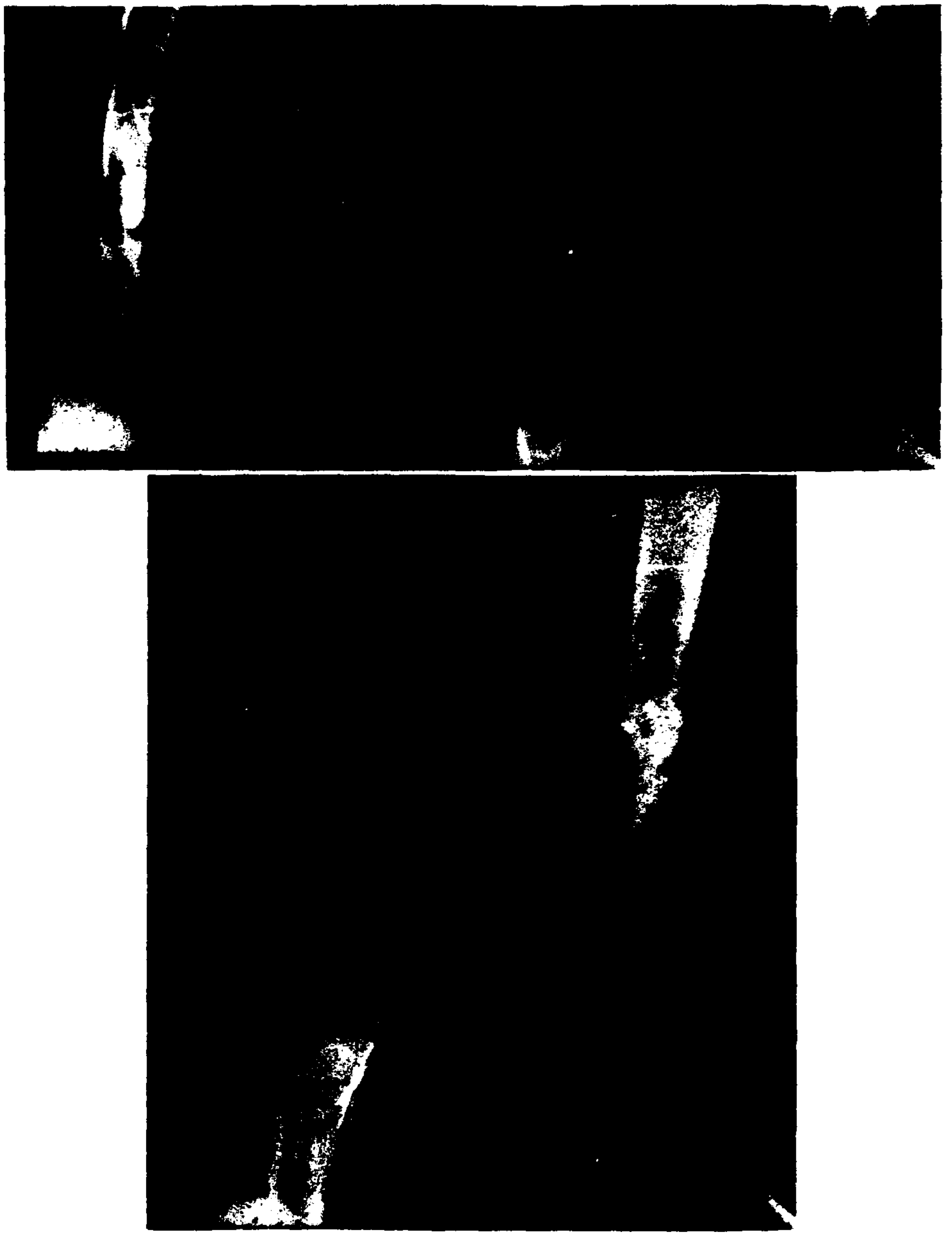

FIGURE 114.—Management by bone grafting of un-united fracture of right humerus at junction of middle and lower third of shaft. (Top) Anteroposterior roentgenogram (left) showing un-united fracture. Anteroposterior (middle) and lateral (right) roentgenograms, 6 August 1945, 3 months after iliac cancellous and cortical grafts had been placed across fracture site without internal fixation. (Bottom) Anteroposterior and lateral roentgenograms, 25 November 1945, 6 months after operation showing solid bony union. (Rhinelander, F. W.: The Use of Iliac Bone Graft in Bone Defects. [Unpublished data.])

Drainage developed in six of 19 old compound fractures in which plates and iliac strip grafts were used, in three instances as the result of closure under tension because the indicated plastic surgery had not been performed previously. In the fourth case,

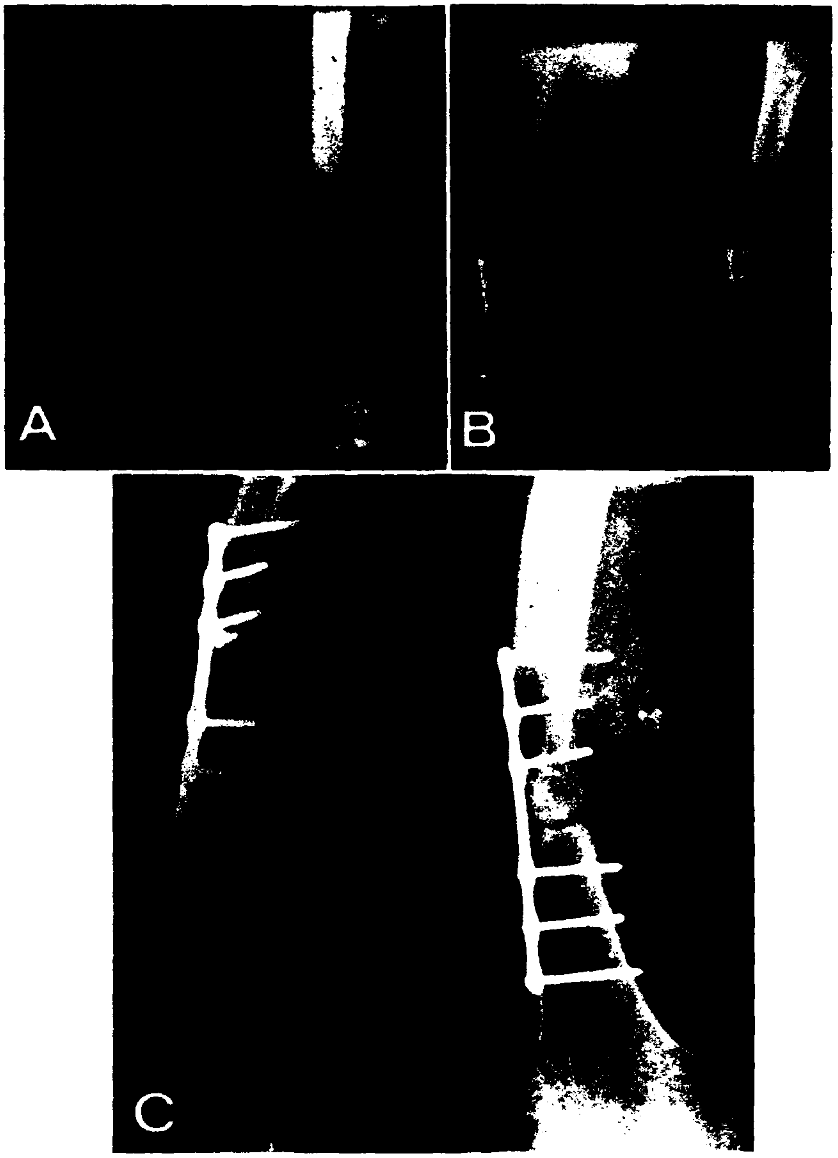

FIGURE 115.—Management by bone grafting of un-united fracture of right femur at junction of middle and lower thirds. A. Lateral and anteroposterior roentgenograms showing nonunion, 15 May 1945. B. Same, 21 August 1945, after osteotomy, grafting with iliac strip grafts, and fixation with plate and screws on 9 July 1945. C. Same, 5 November 1945, 4 months after operation. Union is progressing, though obliteration of the fracture line is, as usual, slow in a mid shaft fracture. (Rhinelander, F. W.: The Use of Iliac Bone Graft in Bone Defects. [Unpublished data.]) [The use of cancellous iliac grafts by Captain Rhinelander is indeed interesting. It is unfortunate that, in some instances in the series, not enough attention was paid to the necessity for adequate full-thickness skin coverage of the fracture site before bone grafting.—M. C.]

the plate was not adequately fixed in position, which predisposed to tissue necrosis and infection. In the two other cases, no error in judgment or technique was apparent.

In another case handled by this technique, delayed absorption was evident about two of the screws; infection was identified by culture when the plate was removed, and only a narrow zone of fibrous union was present.

The analysis of these cases indicates that the chances of infection were much greater when iliac grafts were supplemented by plate fixation, though the combined technique, when correctly carried out, had a number of advantages. The operation was relatively rapid and nonshocking. The assistance of a second team was not required as it was when a tibial graft was used. A metal plate was easily applied, and could be twisted to obtain good fixation while proper relative rotation of the bone fragments was maintained. A tibial onlay, in the same circumstances, would have required more stripping of periosteum. When it was not used, the patient became ambulatory sooner, did not require a brace, and ran no risk of late fracture at the donor site.

Postoperative Complications

Most postoperative orthopedic complications in this series have been discussed in connection with special techniques. In addition:

Postoperative atelectasis, which cleared up in a few days, developed in four patients, following ether anesthesia. One patient with an abnormality of the external urinary tract experienced retention for 6 weeks and another had severe hiccoughs for 4 days. In both cases, ether anesthesia had been used.

Cellulitis developed in an extensively scarred leg 6 weeks after iliac chips had been inserted into a large, infected tibial defect. The infection cleared up after 5 days of treatment by elevation, warm packs, and sulfadiazine. The causative organisms were not sensitive to penicillin.

In another infected wound, the donor site of a split skin graft, applied in conjunction with iliac grafts, became infected.

Drainage from the iliac donor site occurred in five patients, in each instance in connection with hematomas, and in four instances, in clean wounds. In a sixth case, a hematoma in a posterior wound was aspirated three times and cleared up without drainage.

Conclusions

The experience in this series of 104 bone grafts seemed to indicate that, when the danger of lighting up dormant infection was ever present, the safest method of employing iliac grafts was in the form of multiple thin strips or chips, without supplementary metal fixation. This was particularly true in the tibia, where coverage by healthy skin was often difficult to achieve. If a suitable surgical technique was employed, excellent bony union could be anticipated, though immobilization had to be maintained for a relatively long time. At certain sites, especially in the femoral shaft and near the elbow joint, the advantages of internal fixation generally outweighed its dangers. The circumstances of the individual case determined

whether massive onlay grafts or metal plates should supplement the iliac strip grafts.

By the use of cancellous iliac chips, long bones could be reinforced while deep drainage was still persistent, with a decrease, or at least no increase, in the anticipated healing time. Given a favorable case of infected nonunion of the tibia, progress was essentially the same as if a clean bone grafting operation had been performed.

In operations on bones of the feet, elimination of deeply rooted drainage was the major problem. It was a slow process, but a high degree of success was obtained by the use of cancellous iliac chip grafts, especially in the os calcis. Application of pedicle grafts soon after the iliac grafts had become firmly incorporated in granulations (which required about 6 weeks as a rule) curtailed the total healing time.

If satisfactory results are to be obtained with iliac bone grafts, a high degree of technical care must be exercised. Preliminary debridement must be absolutely complete. No cortical bone whatsoever should be introduced into the wound. Cancellous chips should be small and thin, not exceeding, on the average, 1.0 by 0.5 by 0.2 centimeters. As Mowlem showed, a large mass of much smaller chips can lead to sclerosis (*18*). Good postoperative drainage must be provided. The closed plaster treatment, with infrequent redressings, is the procedure of choice. If necrotic chips are found when the wound is redressed, they should be removed at once. A small subcutaneous drain in the donor wound for 48 hours will reduce the likelihood of hematoma formation and later drainage.

OPEN BONE GRAFTING

At one station hospital in the Zone of Interior, between August 1943 and January 1944, 11 patients with old, un-united fractures of the long bones, with varying degrees of active infection, were treated by elective open bone grafting. Sequestra were removed at a preliminary operation, and 2 to 4 weeks later, a massive bone graft was applied. The wound was left open and packed with petrolatum-impregnated gauze, and a cast was applied. The graft failed in every instance and, in a number of cases, did actual harm.

This method of treatment was contrary to established principles of bone grafting and was not approved by the Consultant in Orthopedic Surgery in the Surgeon General's Office. It was discontinued as soon as it was discovered, and the patients were all put under the care of Maj. William F. Stanek, MC, at Winter General Hospital, Topeka, Kans. The experience is presented in detail because the value of strict observance of basic surgical principles is most clearly shown when, as in this instance, their violation produces unfortunate end results. The summary is an abstract of Major Stanek's report to the Consultant in Orthopedic Surgery, of the Surgeon General's Office (*19*).

In no case in this series could any justification be found for the insertion of a bone graft into an actively draining wound. The procedure violated all the principles of bone grafting, which include:

1. Placement of the graft in normal, healthy tissue.
2. Previous excision of sclerotic and scarred tissue from the graft bed as well as from the bone.
3. Replacement of unhealthy tissue with normal subcutaneous tissue and skin, obtained by tube or pedicle graft if necessary.
4. Preoperative elimination of all signs of inflammation, including edema, rubor, and calor.

Details of previous treatment of these 11 cases, three of which were simple and eight compound fractures, are given in table 8. It should be noted that five patients did not receive penicillin after operation, and that two of these five also received no sulfonamide therapy.

Two of these patients had been treated by open reduction before they entered Winter General Hospital, and another had been treated by Roger-Anderson external fixation and by sliding and onlay grafts. These unwise procedures increased the difficulties of later treatment. Other errors included little attention to nerve injuries. All the attention, in fact, was concentrated on the reestablishment of bony continuity.

As soon as these patients came under his care, Major Stanek removed all the grafts, even those that had been placed only 2 to 4 months before. Obviously, grafts that were completely exposed, white, with granulation tissue growing beneath them, and at times with a space of one-fourth of an inch between them and the nearest soft tissue stood no chance of taking. Examination before the grafts were removed showed absorption about the heads of the screws, profuse drainage, and less rather than more evidence of the union originally shown to be present by roentgenograms. Removal of the graft and screws promptly reduced drainage. Immobilization was continued until it was clear that there was no chance of union. Then an effort was made to increase motion in adjacent joints and improve the local circulation, so that definitive surgery would have a better chance of success.

At the end of a year after open grafting, five patients had been discharged on Certificate of Disability for Discharge and six were still in Army hospitals. Eight fractures were still un-united, and in the other three, union in only one, a fracture of the humerus, could be considered satisfactory. A patient with a united fracture of the femur had a 2-inch shortening of the leg and a sciatic nerve paralysis. The tibia that had united was the site of osteomyelitis throughout the length of the shaft. In Major Stanek's opinion, the fractures in both the humerus and the tibia might have united without grafting.

Functionally, the results were estimated as good in one case, fair in five, and poor in one. No evaluation was made in the other four cases. The good result occurred in the fracture of the humerus, which, as just noted, would probably have healed without surgery. Regardless of the functional

TABLE 8.—*End results in 11 open grafting*[1] *operations, Winter General Hospital, August 1943–June 1944*

Case No.	Location and type of fracture	Nerve injury		Previous treatment	Postoperative therapy		Status 1 year postoperative				Need for original graft
		Preoperative	Postoperative		Sulfonamides	Penicillin	Union	Function	Duty status	Further surgery needed	
1	Radius, ulna, compound.	Yes	Yes	Debridement, cast	Yes	No	No	None	In hospital	Yes	Yes.
2	Ulna, compound	Yes	Slight	Debridement, cast	Yes	No	No	Fair	CDD	No	?
3	Ulna, radius, dislocation.	No	No	Open reduction	No	No	No	Fair	CDD	No	Yes.
4	Radius, compound	No	Yes	Debridement, cast	Yes	No	No	None	CDD	No	Yes.
5	Radius, ulna, simple	No	Yes	Cast	No	No	No	Fair	CDD	No	Yes.
6	Upper 1/3 humerus, compound.	No	No	Cast	Yes	Yes	Yes	Good	CDD	No	No.
7	Upper 1/3 humerus, simple.	No	No	Open reduction, plating.	No	Yes	No	None	In hospital	Yes	?
8	Femur, compound	Yes	Yes	Traction, plating	No	Yes	Yes	Poor	In hospital	For nerve	Yes.
9	Tibia, compound	No	No	Traction	Yes	Yes	Yes	Fair	In hospital	No	No.
10	Tibia, compound	No	No	Traction	Yes	Yes	No	None	In hospital	Yes	?
11	Tibia, compound	No	No	Roger-Anderson fixation, sliding and onlay grafts.	No	Yes	No	Fair[2]	In hospital	No	Yes.

[1] The graft was removed in every instance as soon as the patient was seen.
[2] Functional result secured by cross-union of tibia and hypertrophied fibula.

Source: Report, Maj. William F. Stanek, MC, to Col. Leonard T. Peterson, MC, 16 Feb. 1945, subject: Non-Union of Fractures of the Long Bones. Results of Treatment by Open Grafting.

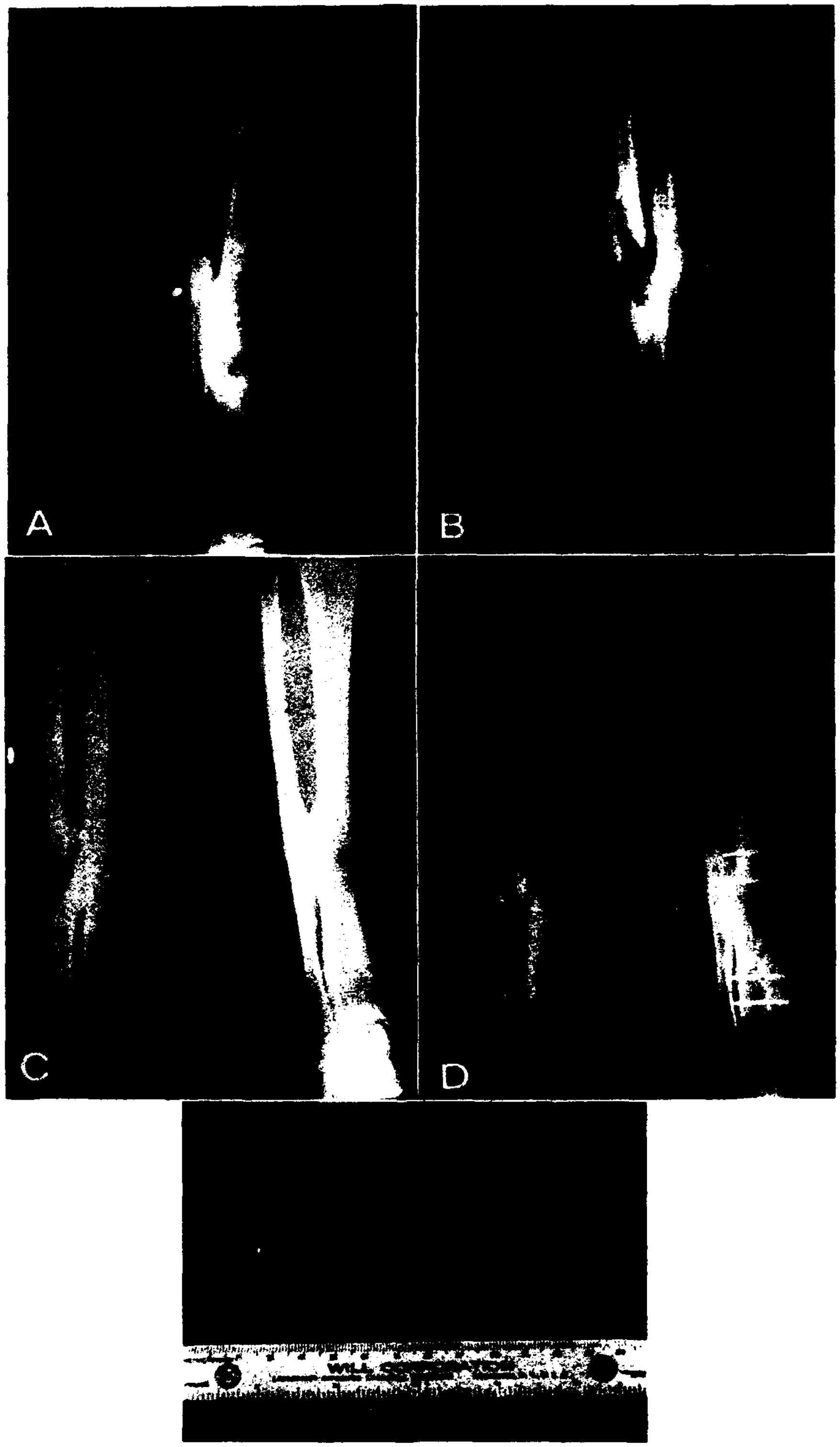

FIGURE 116.—*See opposite page for legend.*

results obtained, very little credit can be given to the graft that was applied, since, as in all the other fractures, it had to be removed.

This unhappy experience again makes certain principles clear:

1. All loss of bone substance is not necessarily an indication for bone grafting.

2. Time will heal many fractures and should always be given a chance.

3. The function of an injured limb must be evaluated and some assurance given of increasing its functional usefulness before grafting is undertaken.

4. This experience again makes clear that surgical principles cannot be violated and that open grafting, which violates them, will almost invariably end in total failure.

The following case history is typical of the histories of the other cases in this series:

Case 2.—A corporal, struck by an automobile on 1 May 1942, suffered a compound fracture of the right tibia and fibula (fig. 116). Roger-Anderson external fixation, which replaced the original splinting on 11 May, was removed on 2 July. On 25 September, a sliding bone graft was applied to the tibia, and three onlay grafts were inserted on 14 November. Portions of the graft were removed on 26 July 1943.

The patient was transferred to Winter General Hospital on 13 November 1943 for treatment of nonunion of the tibia and secondary osteomyelitis.

Roentgenograms taken on 26 November revealed a healed fracture of the right fibula and an un-united fracture of the right tibia, 5 inches above the ankle joint, with sclerosis of the bone. The bone graft present was partly destroyed and absorbed. At operation on this date, the fracture line was exposed and all free fragments of bone were removed. The wound was packed with petrolatum-impregnated gauze and a cast was applied.

At a second operation on 10 December, the fracture of the right tibia was exposed subperiosteally and all soft tissue in the defect was removed. The bone ends were lined up and position was maintained with a dual graft secured from the

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FIGURE 116.—This case history is cited and illustrated in detail because the treatment afforded this soldier for a compound fracture of the right tibia and fibula was most unorthodox and equally unfortunate. It kept him hospitalized from 1 May 1942 through December 1944 and left him with an un-united fracture of the tibia. A and B. Anteroposterior and lateral roentgenograms of right leg, 26 November 1943, showing union of fibular fracture and nonunion of tibial fracture. At this point, adequate debridement of the wound and removal of all necrotic bone and loose fragments or sequestra would probably have permitted successful bone grafting if this procedure had been supplemented by split-thickness skin grafts and perhaps later by a full-thickness cross-leg pedicle graft. C. Lateral and anteroposterior roentgenograms, 17 February 1944, showing healed fracture of fibula and un-united fracture of right tibia, with dual grafts from left tibia fixed to it by screws. These roentgenograms were made almost 10 weeks after application of the grafts, at which time the wound was "packed with petrolatum-impregnated gauze and left open." D. Oblique and anteroposterior roentgenograms, 9 August 1944, 5 months after removal of grafts, screws, and various sequestra which had caused continuing profuse drainage. Note cross union of both upper and lower tibial fragments to the united and somewhat hypertrophied fibula. E. One of the necrotic tibial grafts removed on 7 March 1944. (Report, Maj. W. F. Stanek, MC, to Col. L. T. Peterson, MC, 16 Feb. 1945, subject: Non-Union of Fractures of the Long Bones. Results of Treatment by Open Grafting.)

opposite tibia. The bony defect was tightly packed with broad slivers secured from the crest of the right ilium. The wound was packed with petrolatum-impregnated gauze and left open.

A culture on 30 December 1943 showed *Staphylococcus aureus* and *Bacillus pyocyaneus* in the wound. Roentgenograms taken on 10 January 1944 showed the fracture in good position, with additional bone in the mid portion, but no fresh callus was seen through the cast. When a new cast was applied on 20 January, the screws were tightened in the graft. The bone chips that had been packed into the defect were slightly loose.

When the cast was removed on 17 February, the wound was found to be 10 inches long and 3 inches wide. In the center was a 6-inch tibial graft, with three screws exposed, and with numerous bone chips lateral to it. The distal end of the proximal tibial fragment was also exposed. On the medial side, epithelization had taken place beneath the graft, and there was a gap of one-fourth of an inch between the epithelium and the base of the graft. The granulations appeared clean, but the exposed end of the tibia was necrotic.

The grafts were not removed at this time, to give them a fair chance to take. The cast was replaced. On 1 March, a window was cut into it because of profuse drainage. The organisms present when cultures were made in December 1943 were still present.

The screws and graft were removed on 7 March and the patient was started on penicillin intramuscularly, which was continued until 12 March. Ten days later, there was no area of exposed bone. From this time until closure of the wound, chlorophyll solution was used on the exposed surfaces.

At intervals during March 1944, small pieces of necrotic bone were extruded. At the end of the month, roentgenograms showed secondary osteitis in and about the tibial fracture, which was still un-united. There was moderate absorption throughout the fracture line, and marked sclerosis of the bone in this area.

Since there seemed no possibility of union through the fracture site and since the fibula was solid, the cast was discarded and a long-leg brace was substituted for it. By 20 June, the soft tissues were healed, but the anterior surface of the lower leg was covered only with a thin layer of epithelium. The broad scar broke down under the slightest trauma. It was excised, a small sequestrum was removed, and the wound edges were approximated.

Thereafter, improvement was progressive, except for occasional episodes of swelling and redness and the extrusion of an occasional small sequestrum. On 1 December 1944, the patient was walking without support, with his weight carried on the hypertrophied right fibula. Roentgenograms showed some union of both fragments of the tibia to the fibula and gradual obliteration of the fracture line across the tibia.

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CHAPTER XIV

Adjunct Therapy

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GENERAL CONSIDERATIONS

Infection was not the problem in orthopedic injuries in World War II that it had been in World War I. Surgery was more soundly based and more effective, including, as it did, early and adequate first aid, early and complete debridement, delayed primary wound closure, repeated sequestrectomies as necessary to prevent the development of chronic infection and permit wound healing, and other surgery as indicated. Surgeons were better trained, from those who did the original debridement to those who did the final reconstructive surgery. Finally, adjunct therapy, including the administration of antibiotic agents, the availability of whole blood and plasma, and the use of other supportive therapy all played an important—though by no means the most important—role in the improved results.

A brief chapter on adjunct therapy is, therefore, necessary in this volume, even though its components are described in detail in other volumes:

Blood and plasma transfusion and other resuscitative and therapeutic measures in the volume on the blood program (*1*).

General preoperative preparation and supportive therapy in the same volume as well as in the second general surgery volume (*2*) and the volumes dealing with orthopedic surgery in the Mediterranean (*3*) and European (*4*) theaters.

LOCAL PREOPERATIVE ORTHOPEDIC PREPARATION

While various methods of skin preparation were used before operation, those surgeons who did not use 48-hour preparation (repeated 24 hours before operation) practically always used the 24-hour technique. The surgical field was shaved closely, then scrubbed for 10 minutes with soap and water, washed with alcohol and ether, and wrapped in sterile towels. Moist dressings were not used; the resulting maceration of the skin would have been an invitation to infection. It was also best to omit the local use of any antiseptic solution in the preoperative preparation. Some patients

were sensitive to one antiseptic or another, and the ensuing skin reaction would have delayed surgery.

Skin preparation on the operating table included the local cleansing just described, after which the skin was painted with tincture of iodine, which was removed with alcohol.

ANTIMICROBIAL THERAPY

In World War II, there were two radically different approaches to the use of antimicrobial agents in military surgery (*5*). By the first, these agents were used "to permit delay in wound surgery, and minimize the completeness of the excision of dead tissue." The second approach used these agents "to extend the scope of surgery and achieve a perfection in results previously considered impossible."

After the brief and unhappy experience with the closed plaster technique of fracture management in the first months of fighting in North Africa (p. 255), the second of these approaches became official Army policy in that theater and eventually in all theaters. It was a policy based on certain physiopathologic facts:

1. If dead or devitalized tissue is not completely excised at initial wound surgery, infection is a likely outcome.
2. Once a wound infection has developed, necrosis of living tissue is likely to follow, and a vicious circle is established.
3. Antibiotic therapy, whether by use of the sulfonamides or penicillin, cannot be effective, either systemically or locally, in tissues with little or no vascularity, including sinus tracts with surrounding cuffs of dense scar tissue; bone abscesses with chronically infected granulation tissue which will become dense scar tissue in the process of healing; sequestra; and the areas of eburnated bone commonly found in chronic osteomyelitis.

The policy of wound management that finally evolved in World War II was based on complete debridement of the wound at initial wound surgery; nonclosure of the wound; immediate immobilization of the extremity; closure of the wound at reparative surgery, preferably on the fourth postoperative day or as near the fourth day as possible; and the systemic, but not the local, use of the sulfonamides, which were replaced by penicillin as soon as it became generally available. Of the approximately 25,000 wounds managed by this regimen in the Mediterranean theater up to February 1944, healing occurred in 95 percent. There was no loss of life. There were no serious complications. And incomplete debridement was the explanation of practically every failure. Antibiotic agents, in short, were not a substitute for good surgery, but they were of great adjuvant value, in that they made radical surgery possible without the risk that localized infection would become disseminated or assume an invasive character.

In the report in which these policies were stated, Col. Edward D. Churchill, MC, wrote (*5*):

The topical use of sulfonamides appears to contribute nothing to the favorable results of reparative wound surgery. Parallel series of closures show as satisfactory or better results without the topical application of sulfonamides at the time of suture, as with it. Penicillin therapy is entirely unnecessary as an adjunct to the usual reparative surgery of soft-part wounds. It is used parenterally for cases of established infection and in the reparative surgery of complicated wounds.

The primary closure of combat wounds was never official policy, and in the isolated cases in which it was practiced, contrary to regulations, the results were usually unsatisfactory, regardless of whether or not antibiotic agents were employed.

THE SULFONAMIDES

Administrative Considerations

Sulfanilamide tablets were included in the first aid (Carlisle) packet in use when the United States entered the war, and the injured man was supposed to take one immediately after wounding. In November 1942, sulfadiazine tablets were substituted. Circular Letter No. 164, the Surgeon General's Office (*6*), which contained this information, provided for instruction in the use of the tablets by the unit medical officers and called attention to the toxic reactions described in War Department Technical Manual 8–210, "Guides to Therapy for Medical Officers" (*7*). Large amounts of water were supposed to be taken with each pill, a completely impractical direction in many combat situations.

Circular Letter No. 1, the Surgeon General's Office, dated 2 January 1941 but not released until 1 May 1941 (*8*), described the current availability of the sulfonamide drugs (sulfanilamide, sulfapyridine, and sulfathiazole) and gave general directions for their use, together with a warning of their potential toxicity and instructions for observation of the patient during their use. More detailed instructions were given in Circular Letter No. 105, the Surgeon General's Office, 17 October 1941, prepared by the Committee on Chemotherapeutic and Other Agents, Division of Medical Sciences, National Research Council, at the request of The Surgeon General (*9*).

First aid kits also contained first powdered, and later crystalline, sulfanilamide, which the wounded man was supposed to apply to his wound whenever possible. This item was withdrawn from parachute, Arctic, aeronautic, and motor vehicle (12- and 24-unit) first aid kits in Circular Letter No. 100, of the Surgeon General's Office (No. 32 Supply), 13 July 1943 (*10*). Circular Letter No. 142, Surgeon General's Office (Supply No. 41), 31 July 1943, also provided for the removal of sulfanilamide "in sterile individual double-wrapped envelope" from first aid kits (*11*). Circular Letter No. 1, the Surgeon General's Office, 1 January 1944 (*12*), provided for its deletion from the Carlisle first aid packet.

The Pearl Harbor Experience

It will be remembered that the sulfonamide drugs had been in use only a few years when the United States entered World War II. There was great faith in their potentialities. Some surgeons, in fact, believed that their use would render wounds clean without debridement or other surgery, though very few were as euphoric as this.

On the other hand, the local and systemic use of the sulfonamides received high praise for the excellent results achieved in the wounds sustained at Pearl Harbor. This held not only for the surgeons who used these agents there in the immediate management of the wounded (*13*), but also for the widely experienced and level-headed orthopedic and other surgeons who examined the patients later in Hawaii and still later in the Zone of Interior (*14–16*). In evaluating all of their comments, it should be borne in mind that their experience to date, however extensive, did not include battle injuries. Dr. LeRoy C. Abbott, who studied the casualties returned from Pearl Harbor at Letterman General Hospital, San Francisco, Calif. (p. 263), stated that, by the local application of sulfanilamide to the wounds, "many bad situations were undoubtedly saved." He recommended the administration of 4 grams of sulfanilamide daily for 4 days after wounding and added that "the drug, of course, should be applied to the wounds locally."

Dr. Abbott's report was made to the Subcommittee on Orthopedic Surgery, Committee on Surgery, National Research Council, at the 24 February 1942 meeting, the first held after the attack on Pearl Harbor (*14*). It is instructive to compare these early comments with those of Col. J. A. MacFarlane, RCAMC, Chief Medical Consultant, Canadian Armed Forces, at the 2 June meeting of the subcommittee (*17*), remembering that he was speaking from a long (2½-year) experience and far more extensive observations (Norway, France, North Africa). Early in the British and Canadian experience, Colonel MacFarlane said, there had been a tendency to rely too heavily on both local and systemic sulfa therapy. There were numerous indications for the use of these agents, but no drug could replace thorough, careful debridement. In a series of 60 controlled injuries, half treated with sulfonamides and half with very thorough debridement without drugs, there was no essential difference either in the healing time or in the progress toward recovery. Essentially the same conclusions were reported by the Subcommittee on Surgical Infections to a joint meeting of the Committee on Surgery and the Committee on Chemotherapeutics and Other Agents, National Research Council, on 3 September 1943 (*18*).

In his report on the Pearl Harbor experience, Col. John J. Moorhead, MC, said that the lecture he had given on 5 December 1941, 2 days before Pearl Harbor, before the Honolulu County Medical Society (then as a civilian consultant) was "virtually a dress rehearsal" for the event (*13*). It was entitled "Treatment of Wounds, Civil and Military," and it stressed early, adequate cleansing of the wound; adequate debridement; nonclosure; placement in the wound of an adequate amount of sulfanilamide or sulfathiazole; and systemic sulfonamide therapy.

Colonel Moorhead attributed the almost complete absence of purulent exudate and other complications in the wounds sustained at Pearl Harbor to treatment of the wounded within the 6-hour golden period and strict adherence to the surgical principles just stated.

Dr. (later Brig. Gen.) Isidor S. Ravdin and Dr. (later Col., MC) Perrin H. Long, who observed the Pearl Harbor casualties in Hawaii and later in the Zone of Interior (*14, 15*), emphasized the importance of nonclosure of the wounds and of good surgery in the excellent results obtained. Of the sulfonamides they wrote:

> Finally, there can be little doubt but that the local and oral use of the sulfonamide drugs contributed markedly to the splendid condition of the wounds and the absence of infection in these patients, which has been noted and remarked upon by all who have seen them. As a result of these observations, it would now seem a wise procedure to implant crystalline sulfanilamide into all wounds as soon as possible after they have been inflicted, and experience in Hawaii has shown that if this is done, the usual dictum that *it is unsafe to debride a wound when a period of more than 6 hours has elapsed since the wound has been incurred, can be disregarded.* However, it should be remembered that *wounds should always be debrided as soon as possible.* Experience has shown it to be wise to begin oral therapy with a sulfonamide drug as soon as possible after the operative procedures have been completed, and that for this purpose a dosage schedule of 4.0 to 6.0 grams of drug per day for a period of from 7 to 10 days after operation would seem advisable.
>
> Dressings of the wound subsequent to operation should be carried out with a strict surgical technique in order to prevent secondary infection, and in every instance when wounds are dressed, they should be sprinkled with crystalline sulfanilamide until complete healing has taken place.

Local Sulfonamide Therapy

The high hopes originally felt for the use of the sulfonamides in combat-incurred wounds were not fulfilled. They continued to be used systemically on various indications, and with great benefit, even after penicillin became available, but by the middle of 1943, their local application had been discontinued as not useful and frequently harmful. War Department Technical Bulletin (TB MED) 147, issued in March 1945, noted that "The routine local use of chemotherapeutic agents has been abandoned" (*19*). It was not, however, until Change 1 was issued on 9 January 1947 that the prohibition against the use of crystalline sulfonamides as an emergency aid measure was made mandatory. It was then directed that this agent should not be applied after surgery to wounds not involving the serous cavities, and its local use in cavities was not recommended.

The position of the Army Medical Department that the local use of sulfonamides was not helpful and was sometimes harmful was not accepted without protest by civilian orthopedic surgeons, who, however wide their civilian experience, had not personally observed and treated combat injuries. Maj. Champ Lyons, MC, at the meeting of the Southern Surgical Association in December 1945 (*20*), reported the results of a study of wound management in the Mediterranean theater, closing with the remarks:

> The topical use of antibacterial agents was contraindicted by the philosophy of reparative wound management * * * these investigations have affirmed the sound-

ness of the listerian principle of treating the local wound by surgical measures * * *. Experience in wound management justifies the abandonment of local use of any chemical agent in a wound for its supposed antiseptic effect in the prevention or treatment of infection * * *. Specific chemotherapy, given by the systemic route, is a proper adjuvant to an expanded surgical program for more effective wound management.

Dr. J. Albert Key took exception to the condemnation of the local use of sulfonamides (*20*). He could not understand why "the Army threw [them] out of the window before they had anything adequate to put in their place." It was his opinion that, with adequate local and systemic chemotherapy, radical excision could be modified. Major Lyons, in concluding the discussion, took the firm position that it was impossible to compromise with the excision of devitalized tissue. "The total military experience," he said, "condemns any attempt at wound treatment short of removal of all devitalized tissue."

A Routine of Sulfonamide Therapy

While techniques of sulfonamide therapy varied somewhat from hospital to hospital, the plan used at Halloran General Hospital, Staten Island, N.Y., may be taken as typical:

1. Sulfanilamide was the drug of choice for parenteral use.
2. Sodium sulfadiazine was also used intravenously.
3. Sulfadiazine was the drug of choice for oral therapy, followed by sulfanilamide and ulfathiazole in that order.
4. If the patient was not voiding at least 1,000 cubic centimeters per day, the blood concentration of the drug was calculated daily and the dose adjusted downward as indicated. If oliguria or urinary suppression occurred, sulfonamide therapy was discontinued at once and fluids were forced by mouth, supplemented by glucose infusions.
5. Before the local use of sulfonamides was abandoned, crystalline sulfanilamide was used for this purpose. The area of the wound was sprinkled with enough of the drug to frost it each time the dressing was changed. Purulent and necrotic material was always removed before the sulfanilamide was applied.

PENICILLIN

General Considerations

Any discussion of penicillin in World War II must begin with the emphatic statement that valuable as this agent was, it was simply one component of the triple regimen of wound management that was developed in the Mediterranean theater and later applied to all theaters (*3*). This regimen consisted of:

1. The liberal use of whole blood to correct secondary anemia and hypoproteinemia, supplemented by other supportive measures.

2. Aggressive surgery, which meant, among other things, complete debridement with nonclosure of the wound, followed by closure by delayed primary suture, preferably performed between the fourth and seventh days after initial wound surgery.

3. The use of penicillin on indications, which meant, from the orthopedic standpoint, its use in skeletal and joint injuries and in wounds with extensive muscle damage. Casualties with such wounds were put on penicillin as soon as they were received after wounding, kept on it during the performance of both initial and reparative surgery, and maintained on it until all risk of infection was considered to be past. Later in the war, penicillin was used prophylactically. Originally, not enough was available for it to be used in this manner.

It was the total regimen just outlined, not the greater potency of one component or another, that was responsible for the success of the new policy in World War II. If, however, it should be necessary to select the factor of greatest importance, there would undoubtedly be general agreement that it was aggressive, complete debridement.

Early Investigations

The original instructions for the penicillin testing program were set forth in Circular Letter No. 125, the Surgeon General's Office, dated 16 July 1943 (*21*). This letter was rescinded on 12 February 1944, when War Department Technical Bulletin (TB MED) 9 (*22*) was published. This was a comprehensive article on all aspects of penicillin, with full directions for its use. Its orthopedic use was limited to infected combat-incurred fractures, osteomyelitis, and suppurative arthritis.

When penicillin first became available for clinical use, pilot units were established at Bushnell General Hospital, Brigham City, Utah, on 1 April 1943, and at Halloran General Hospital on 3 June 1943 (*23*). Both units functioned as schools, to which selected medical officers were sent for month-long courses of training in "an overall program seeking definition of the effectiveness of the drug in surgical infections." The program, which was limited to the use of penicillin in surgical infections, covered methods of administration, dosage, reactions, the management of acute pyogenic infections, and the management of chronically septic compound fractures. The experience with chronic infections included a study of the bacteriology of war wounds and the anemia of chronic sepsis.

Investigations were later carried out at Ashford (White Sulphur Springs, W. Va.), Brooke (San Antonio, Tex.), Kennedy (Memphis, Tenn.), Lawson (Atlanta, Ga.), Letterman, McCloskey (Temple, Tex.), Percy Jones (Battle Creek, Mich.), Valley Forge (Phoenixville, Pa.), and Walter Reed (Washington, D.C.) General Hospitals. Each of these investigations was headed by a medical officer already trained in the use of penicillin.

The coordinator of the program at Halloran General Hospital was Major Lyons. When he was ordered overseas, some 6 months after the institution of the study, Maj. (later Lt. Col.) George K. Carpenter, MC, became director of the penicillin-orthopedic program. Capt. (later Maj.) Karl F. Mech, MC, served as ward officer on the penicillin wards.

The extensive report on the original studies made by Major Lyons in December 1943 included the following data:

1. *After* penicillin had been administered by various routes, it was found that it should be given intravenously or intramuscularly, preferably by the latter route, since it was excreted rather rapidly by both routes but relatively more slowly by the intramuscular route. It was not effective by mouth.

In the original investigations, local therapy was preferred whenever its use was practical because it was more economical than systemic therapy. A high local concentration was considered particularly useful to reduce the intensity of infection with proteolytic clostridia. As time passed, the local application of penicillin showed no particular advantage over its systemic use, and by the end of the war, this technique was seldom used.

2. The precise dosage of penicillin was not established. There was considerable variation in the stability of prepared solutions, and methods of assays varied by as much as 25 percent. Because the supply of penicillin was at first so limited, the—proper—policy had been to use the dose that was minimally adequate rather than to attempt to determine the dose that would be maximally tolerated.

3. Micro-organisms varied in their response to penicillin. It proved an effective antibacterial agent in the treatment of acute infections caused by hemolytic and nonhemolytic streptococci, pneumococci, gram-negative diplococci, mixed infections caused by gram-positive bacteria, and actinomycosis. Hemolytic streptococci and pneumococci were highly sensitive to a dosage of 90,000 units daily, in divided doses of 15,000 units intramuscularly every 4 hours for 3 to 5 days. Staphylococci were about four times more resistant, and dosages of 200,000 to 400,000 units, given in 25,000-unit doses every 3 hours, were necessary, depending upon the severity of the infection. Gram-negative bacilli were resistant to penicillin. Mixed infections with both gram-positive and gram-negative bacteria might be benefited by the effect of the drug on susceptible species. Anaerobic cellulitis due to the proteolytic bacteria present in putrid wound infections also responded, though the bacteria tended to persist in the presence of devitalized tissue and wound exudates. *Pyocyaneus* was not susceptible, but it was relatively unimportant as a single pathogen.

4. Local applications were made in solution; dry penicillin, whether as a salt or as powder, was irritating. Concentrations averaging 250 units of penicillin per cubic centimeter were generally effective. Higher concentrations were no more effective than the 250–500-unit range.

5. There were many impurities in the earliest preparations of penicillin, and, as might have been expected, a number of toxic reactions occurred, most of them transient. Urticaria was the only serious reaction that had been encountered when this report was made. It did not recur during continued therapy, and no permanent sensitization was apparent at this time.[1]

6. Major deficiencies in red blood cells, hemoglobin, and circulating blood volume were discovered in the course of this study in patients with chronically infected combat-incurred fractures. They are discussed later.

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[1] This statement must be read with the recollection that it was made in December 1943 and that subsequent experiences with penicillin have overturned most of it.

7. Clinically, penicillin proved dramatically effective in staphylococcic osteomyelitis. It was successful in infectious arthritis when it was used parenterally and combined with aspiration-instillation therapy. It was also effective in a number of other conditions. But, at this time, the major orthopedic problem in general hospitals in the Zone of Interior was chronically infected combat-incurred compound fractures, with devitalized bone fragments, sequestra, and retained foreign bodies. Penicillin controlled the anaerobic cellulitis usually present in such infections but otherwise it was effective only if it was combined, as already emphasized, with aggressive, complete surgery. When it was used supplementally in this manner, it was concluded, "* * * [it] permits a direct and immediate surgical approach to the management of septic gunshot fractures. Its role in this regard is analogous to the use of vitamin K for patients with obstructive jaundice. Such a concept emphasizes the limitations of penicillin therapy and designates the supplemental position of penicillin in the overall surgical program" (*23*).

Many of the cases handled with penicillin early in the program might be described as illustrating the groping of the staff to learn how this new agent could influence their surgical procedures. They promptly learned, by hard experience, that it was not the miracle drug it was so often described as being. It was, instead, a powerful adjunct to surgery performed on established principles. Its potency was enhanced by the application of the knowledge, fully learned and appreciated at the time of its introduction, of the importance of the patient's systemic status and of the need for the most careful preoperative preparation. It was never a substitute for surgery.

Topical Application

As might have been expected with a totally new agent, introduced amid the exigencies of war, some of the early techniques of penicillin therapy were largely experimental. The very careful study of its topical use made by Maj. Joseph A. Weinberg, MC, at Birmingham General Hospital, Van Nuys, Calif., is cited in some detail as a case in point (*24*).

The investigation concerned 28 longstanding, chronically infected compound fractures that had been treated by other methods for periods ranging from 2½ to 27 months without response. All were combat wounds, and all were characterized by extensive destruction of soft tissue and bone. Many of the fractures showed funnel-shaped defects. Sixteen involved the tibia or the tibia and fibula. The organisms present, particularly *Bacillus proteus*, had begun to show increasing resistance to penicillin.

The first attempt at topical application was the instillation of penicillin solution (500 units per cubic centimeter) into the wound through a Carrel tube every 4 hours. Improvement was evident, but difficulties of administration made this technique both impractical and unsafe.

These difficulties were overcome when a mixture of penicillin and standard army lubricating jelly (1,000 units per cubic centimeter) was applied directly to the wounds whenever they were dressed. This water-soluble preparation released penicillin readily and its consistency assured

FIGURE 117.—*See opposite page for legend.*

its contact with the wound for several hours. Better results were secured if the wound was first cleansed with hydrogen peroxide instead of physiologic salt solution.

The average time between wounding and the institution of penicillin jelly treatment in these 28 cases was 10.34 months, and between the institution of this treatment and complete healing in the 23 successful cases, it was 1.16 months. Three other patients were progressing favorably when the report was made, and, on the basis that healing was not complete at the time of the analysis, the other two cases were listed as failures. The response to treatment was often spectacular (fig. 117).

Supplemental therapy and the removal of sequestra played their usual important roles.

OTHER ANTIBIOTICS

The first work on streptomycin was done late in World War II, but was not reported until 1946 (*25*). Orthopedic conditions were not included in the original studies, which were limited to soft-tissue infections. Bacitracin was a postwar development.

NUTRITIONAL STATUS AND SUPPORTIVE THERAPY

An important outcome of the work done on penicillin by Major Lyons and his group on chronically infected gunshot fractures at Halloran General Hospital was the demonstration of the nutritional depletion often associated with such fractures and the development of methods for overcoming it. The degree of depletion was variable, but it might be so extreme as to take precedence over all other considerations when the patient was received. A positive nitrogen balance might be established in the presence of continuing infection, but the synthesis of new tissue proteins and the regeneration of red blood cells and hemoglobin were dependent on control of the infection.

The patient in this status presented weight loss, diminished strength and muscle mass, anorexia, and anemia. In the cases observed at Halloran General Hospital, the weight loss was considerable, varying from 5 to 30 kilograms. A loss of 10 kilograms was always clinically obvious. Muscle atrophy and loss of strength preceded weight loss, and improvement in

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FIGURE 117.—Perforating wound of lower third of right femur with marked depression due to loss of soft tissue and bone. A. Anteroposterior roentgenogram showing badly comminuted lower third of femur with considerable loss of bone substance. The fracture has united with minimal deformity. B. Soft tissue wound 20 months after gunshot injury. Exposed bone is partly covered with suppurating granulation tissue. C. Healed wound after treatment with penicillin jelly for 21 days, followed by split-thickness skin grafting of exposed bone surface. (Weinberg, J.: Bull. U.S. Army M. Dept. 5: 419–422, April 1946.)

muscle bulk and strength was evident before significant weight gain when recovery began.

Studies of the distribution of extracellular body fluids carried out by the sodium thiocyanate and Evans blue dye methods showed that the patients, on admission, had interstitial fluid volumes from 4 to 7 liters too great for the standards of their observed weights and significantly larger than the standards for their weights before injury. During convalescence, the interstitial fluid volume values slowly decreased without apparent diuresis. Sedimentation rates were correlated more closely with clinical improvement than any other laboratory determination. Progressive weight gain was seldom apparent before the sixth to eighth week of recovery.

Significant fluctuations in the concentration of serum protein and hemoglobin were correlated with changes in blood volume and were unrelated to penicillin therapy. During periods of hemoconcentration, the urine volume might equal or exceed the fluid intake. Unless, however, the blood volume was known, a single observation of the concentration of serum protein or hemoglobin was not useful and could be misleading. Reductions of 1,500 to 2,000 cubic centimeters in blood volume were recorded, and operation could have been highly dangerous if the decreased values had not been recognized and corrected beforehand. Even minor blood losses in these circumstances could produce ineffective blood volume and shock.

The investigations at Halloran General Hospital also showed deficits in the total quantity of circulating hemoglobin, with normal or nearly normal quantities of plasma protein. The albumin-globulin ratio, which was studied in about 30 cases, did not vary significantly from normal values. Plasma fibrinogen values were constantly elevated. Blood electrolytes were normal.

The major deficiency associated with chronically infected battle wounds was in hemoglobin. It was particularly dangerous because the reduction was frequently masked by hemoconcentration and by normal or nearly normal quantities of hemoglobin in given units of blood. Accurate values could be obtained only when the total circulating hemoglobin was calculated with knowledge of the total blood volume and concentration. Since the practical difficulties of blood volume determinations precluded routine use of such tests, the solution was the clinical assumption that every patient with a chronic infection was anemic.

Liver function studies were not carried out. Prothrombin times were invariably normal, and with normal serum proteins and increased fibrinogen values, it was assumed that the liver function was satisfactory.

Urinary nitrogen tended to be high in these patients (15 to 20 grams per 100 cubic centimeters daily) without increased values for urinary potassium. Positive nitrogen balance could be attained by any regimen that provided a daily intake of 130 grams of protein or more. Since one of the important achievements of penicillin therapy was improvement in the appetite, intakes of 150 to 200 grams of protein were accomplished with relative ease. A series of special dietary tests showed that it was possible to produce a positive nitrogen balance by diet alone, independent of penicillin therapy. A positive balance, however, was not associated with restoration of hemoglobin values unless penicillin was given.

Certain patients who were operated on without supportive intravenous therapy were carefully studied after operation. The hematocrit, hemoglobin, and plasma protein values were relatively stable during the first 48 hours, but the pulse rate was accelerated. On the third or fourth postoperative day, plasma protein concentration was unchanged or increased, but the hematocrit and hemoglobin values were decreased. The blood volume was greatly reduced, and there was a disproportionate reduction in the total quantity of

hemoglobin as compared to the total quantity of plasma protein, but whether these decreases were due to the preferential utilization of hemoglobin, the less rapid synthesis of new hemoglobin, or faulty regeneration of red blood cells was not clear.

These were extremely important observations, which clearly pointed to the need for the administration of whole blood. Specifically, the requirements were established as:

1. Frequent transfusions of whole blood, in 500- to 1,000-cubic centimeter amounts, during the preoperative and postoperative periods.
2. A judicious combination of whole blood and plasma in 1,000-cubic centimeter quantities the day before operation, the day of operation, and the day after, to maintain the circulating blood volume and the positive nitrogen balance.
3. Whole blood in similar quantities once or twice a week thereafter until hemoglobin values were restored and maintained at a level of 15–16 grams per 100 cubic centimeters.

Hemoglobin deficiencies had been expected immediately after wounding, though their extent was not realized. Similarly, it was known that progressive anemia was associated with chronic sepsis, but until these investigations were undertaken, its extent had also not been realized. It had been the practice to determine the hemoglobin value as such, not in relation to the total circulating amounts present. Once the true situation was demonstrated at Halloran General Hospital and later in the Mediterranean theater (*3*), the estimates of blood needed in all conditions were revised upward, and increasing amounts were used as the war progressed and as larger supplies of blood became available.

All of these observations were applicable to orthopedic injuries. In one series of 100 fractures of the femur observed at the 16th Evacuation Hospital in the Mediterranean theater, 28 patients each required between 1,500 and 2,000 cubic centimeters of blood before and during operation, and only nine required no blood at all (*3*).

The following case history is instructive:

Case 1.—A patient with a combat-incurred compound fracture of the middle third of the femur was admitted to Halloran General Hospital with nonunion. A bone graft 4½ months later failed, and a second, 4½ months after the first operation, was equally unsuccessful. The patient, who by this time had been hospitalized for a year, seemed in good general health and was in excellent spirits. For some reason, he had received neither blood nor plasma before either of these operations. The routine laboratory tests gave normal values, but when a blood volume test was run, he was found to have a deficiency of 1,500 cubic centimeters, and a high degree of anemia. During the next 3 months, he received 3,500 cubic centimeters of whole blood, and 6 weeks after the first transfusion, clinical union and callus formation were evident for the first time.

Comment.—This man had no clinical evidence of infection, and perhaps union would have ensued eventually if he had received no blood. It is most uncommon, however, for evidences of union suddenly to appear at the

end of $4\frac{1}{2}$ months if there has been no previous clinical or roentgenologic evidence of its occurrence. The case history shows clearly the importance of evaluating the nutritional status of the chronically disabled patient before major surgery, even if he has no clinical evidence of infection or nutritional deficits.

Vitamin deficiencies.—Another deficiency observed in patients with chronically infected compound fractures during the studies carried out at Halloran General Hospital was a reduction in their vitamin stores, especially vitamin C. Previous investigations had shown that such a reduction delays normal wound healing by interfering with the laying down of collagen. It was, therefore, recommended that all wounded (or burned) patients receive daily supplements of vitamin A (5,000 international units); thiamin (2 milligrams); ascorbic acid (75 milligrams); riboflavin (3 milligrams); nicotinic acid (20 milligrams); and vitamin D (400 international units). These totals were administered daily in two multivitamin capsules. If large amounts of glucose were given by the intravenous routine, 10 to 20 milligrams of thiamin chloride and 100 milligrams of cevitamic acid were added daily to the infusion fluids.

PREOPERATIVE ROUTINE

Based on these observations and on standard practices, an effective preoperative routine included:

1. Blood or plasma or both according to the indications.
2. A high-caloric, high-protein diet, including supplemental feedings. Amino acids were sometimes administered also.
3. Vitamin supplements.
4. Ambulation whenever that was possible.
5. Active assisted exercises of the affected extremity, with local massage to improve the circulation and increase muscle tone.
6. Penicillin. When penicillin first became available, in limited quantities, the sulfonamides were used with it, but by the spring of 1945, combined therapy had been discontinued and only penicillin was used.

Many casualties who were poor risks when this regimen was begun showed surprising improvement within a few days.

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CHAPTER XV

Physical Therapy, Reconditioning, and Occupational Therapy

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Although the policy in this historical series is to avoid, as far as possible, repeating in one volume material which appears in other volumes, that policy is being violated in this chapter. The reason is that physical therapy and its allied specialties, reconditioning (rehabilitation) and occupational therapy, constitute such an integral part of orthopedic surgery that the omission of any mention of them might easily be misunderstood. This brief summary chapter has, therefore, been prepared.

HISTORICAL NOTE

Physical therapy and its related activities represented a new field of endeavor in World War I, but not for the United States (*1*). When it entered the war, it merely had to select and modify existing plans in Allied and enemy countries to meet its special needs.

In France and Italy, physical and educational retraining was conducted under medical supervision and was compulsory as long as a man was in the Army. In England, training was voluntary, even in the orthopedic and "limbless" hospitals which had training shops attached to them. The Belgians, who had no country because it was occupied by the enemy, insisted on compulsory treatment as long as the sick or wounded man required it.

In Germany, the law of 31 May 1906 had created a powerful and well-planned reconditioning organization (Kriegsbeschädigtenfürsong), and all private activities in this field were subordinate to military regulations. In physical therapy, for instance, passive orthopedic movements were not encouraged. Instead, the emphasis was on active gymnastics carried out under military orders.

In Austria and Hungary, physical and other reeducation was obligatory and was entirely controlled by the government. Occupational placement after retraining was under civilian auspices.

Development of U.S. Army Planning and Policies

Shortly after the United States entered World War I, the American Orthopaedic Association and the Orthopedic Section of the American Medical Association jointly selected an orthopedic surgeon to initiate planning for physical therapy and allied specialties in the Army. As soon as he was

commissioned, in May 1917, he was ordered to England, to investigate these activities in the British Army. On 22 August 1917, after his report had been made and other special studies carried out, a Division of Special Hospitals and Physical Reconstruction was set up in the Surgeon General's Office, with four sections:

1. Special hospital sites, buildings, and grounds.
2. Special medical and surgical reconstruction, including the development of plans for treatment of the blind, the deaf, and casualties with speech defects and other conditions requiring specialized care. This division was to be staffed by representatives of all the surgical specialties, including orthopedic surgery.
3. The therapeutic use of physical remedies and of work activities. This division was to develop plans for curative workshops and laboratories, to relate work to medical requirements, and to investigate the use of handicapped men in the military service and in civilian occupations.
4. Information and literature.

Three points were emphasized in the initial planning:

1. Only such activities would be undertaken overseas as might be expected to return the casualties to duty there.
2. Reconstruction work was expected to be under the jurisdiction of the orthopedic department.
3. Military reconstruction was expected to lead, directly and as promptly as possible, to industrial rehabilitation.

On 21 March 1918, an "eminent surgeon," who was an officer in the Medical Reserve Corps, was assigned as Chief of the Division of Special Hospitals and Physical Reconstruction in the Surgeon General's Office and was directed to take immediate steps to coordinate all activities of both military and civilian organizations in this area.

The program was ambitious. The first step was the formulation of a building schedule for the proposed reconstruction hospitals, which were to be equipped to care for, and furnish final treatment to, the sick and wounded and which must be equipped, in addition to the usual facilities, with facilities for all forms of special treatment and for curative workshops.

The multiple changes of organization and planning which the program underwent during 1918 cannot be described within the limits of this space. At the armistice, 11 November 1918, curative workshops had been approved in only four hospitals, and the planned program had to be adapted, in the fastest and most practical possible fashion, to existing hospitals.

Program of Physical Therapy and Vocational Training

A tentative but very detailed plan for physical rehabilitation and vocational training had been submitted to the Secretary of War on 7 November 1917, and a number of the measures recommended in it had been instituted early in 1918 at Walter Reed General Hospital, Washington, D.C., and at the numbered general hospitals at Fort McHenry, Baltimore, Md., and Fort McPherson, Ga.

By the summer of 1919, most orthopedic casualties in need of further therapy had been concentrated at Walter Reed General Hospital and Letterman General Hospital, San Francisco, Calif.; the base hospitals at Fort Riley, Kans., and Fort Sam Houston, Tex.; and 15 numbered general hospitals. Casualties received at them fell into two main groups, (1) amputees, and (2) patients with compound fractures complicated by osteomyelitis.

Physical therapy.—Physical therapy for amputated stumps consisted chiefly of radiant heat and light; massage to mobilize adherent scars and prevent or control edema; mobilization of neighboring joints, to prevent contractures; and instruction in the use of prostheses, which was a matter of major importance.

Treatment of compound fractures with osteomyelitis was directed to the control of chronic inflammatory conditions responsible for massive scar tissue, bone and soft-tissue atrophy, contractures, circulatory impairment, edema, and sluggish granulations. Measures employed included whirlpool, contrast, and paraffin baths; radiant heat and light; and massage. Active motion was always preferred to passive motion, and exercises, games, and recreational sports were used extensively. Curative workshops were adapted to the different requirements of the small and the larger joints of the hand.

Occupational training.—Perhaps more remarkable than the wide range of subjects proposed in the plan for occupational therapy submitted to The Surgeon General in November 1917 was the fact that so many of them were really taught. Between January and June, 1919, instruction included:

Twenty-two academic subjects, ranging from reading to Latin.

Thirty-nine technical subjects, ranging from the subjects usually regarded as occupational therapy, such as weaving and woodworking, to automobile driving and plumbing.

Ten agricultural subjects, ranging from animal husbandry to greenhouse work.

Eight recreational subjects, ranging from military drill to dancing.

Workload

From July 1918 to December 1919, the official records, which are not regarded as entirely accurate, showed 110,638 men registered in the educational program. It is believed that the number was considerably larger. As the value of physical therapy and educational training became more evident, more and more patients were referred for them, particularly patients with orthopedic and neurosurgical injuries. The peak registration (14,884) was in April 1919. The hospital enrollment in these courses rose steadily from 29 percent in January 1919 to 48 percent in May, and 61 percent in November, of that year. These percentages were regarded as surprisingly low, though there were, of course, several explanations: Some patients were ready for immediate discharge when they arrived in Zone of Interior hospitals. Some were never in condition to be benefited by occupational or educational training. Finally, unless a man was to be hospital-

ized for more than a week, there was no point to enrolling him at all. It was estimated that in 1919, probably 35 percent of the total hospital population was ineligible for training for one or another of these reasons and that, of the 65 percent who were eligible, about two-thirds were reached. In some hospitals, the actual registration exceeded 90 percent of the population.

The choice of subject for training depended upon the patient's mental capacity and his previous education. A considerable number of men made their selections with the idea of changing their previous occupations.

The results of physical rehabilitation were reasonably easy to measure, though they do not lend themselves to statistical evaluation. They were generally good. Educational improvement was extremely difficult to measure, but it is known that a not inconsiderable number of patients previously classified as illiterate (no education beyond the first grade) were removed from this category as the result of their postwar training. Even if the hospital stay was no longer than 3 weeks, purposeful educational training was found to be possible.

ADMINISTRATIVE CONSIDERATIONS IN WORLD WAR II

Physical therapy activities in the Surgeon General's Office in World War II were at first handled by an officer in the Surgery Division (*2*). They were made the responsibility of the Orthopedic Branch as soon as it was formally established in that office, in December 1943. Maj. Emma E. Vogel, WMSC, who was in charge of physical therapy activities when they were incorporated into the Orthopedic Branch of the Surgeon General's Office, was an experienced administrator as well as an experienced physical therapist. She continued in charge of personnel and training. The Consultant in Orthopedic Surgery assisted her in matters of policy and in the preparation of directives and other publications.

In War Department Circular No. 281, 6 July 1944 (*3*), physical therapy was made a unit of the orthopedic section in all hospitals. This was a wise arrangement. In most hospitals, from 40 to 50 percent of the patients, and sometimes more, were under orthopedic care, and the closer the cooperation between the chiefs of orthopedic surgery and physical therapy, the quicker and more satisfactory was their rehabilitation. On all his visits to hospitals, the Consultant in Orthopedic Surgery inspected physical therapy facilities and procedures, and in many hospitals, the chief of physical therapy made regular rounds with the chief of orthopedic surgery on the orthopedic wards. No matter what the organizational relation was at any particular time, it was always preferable that the orthopedic surgeon responsible for the patient also be responsible for the direction of the physical therapy he was to receive and that the surgeon's directions, particularly with regard to limitation of activity, should be specific.

PERSONNEL AND TRAINING

Subcommittee on Physical Therapy

The procurement of physical therapy personnel came under discussion even before the United States entered the war. At the (third) meeting of the Subcommittee on Physical Therapy, Committee on Surgery, Division of Medical Sciences, National Research Council, on 6 September 1941 (*4*), it was reported that there were approximately 323 vacancies in this category in the Army Medical Corps. The Veterans' Administration believed that it could operate with 25 additional aides unless the United States entered the war (as it did just 3 months later) and the Army turned over additional duties to it. The Navy needed no technicians at this time and would need none unless the United States entered the war. The present need for technicians in the Armed Forces was, therefore, about 350, about twice the number then needed in civilian hospitals and other medical institutions.

At this time, 16 schools of physical therapy in the United States were approved by the Council on Medical Education and Hospitals, American Medical Association, and four more were in process of formation, at the University of Minnesota (Minneapolis, Minn.), New York University (New York, N.Y.), Washington University (St. Louis, Mo.), and White Memorial Hospital in Los Angeles, Calif. All were under the direction of qualified therapists.

The matter was discussed again at the 2 April 1942 meeting of the Subcommittee on Physical Therapy (*5*). At this time, 125 physical therapists were on duty in the Armed Forces, and it was estimated that an additional 300 would be needed. For 1943, the total requirement would be 1,000. The estimates were regarded as inaccurate.

How to procure the additional technicians needed was a serious problem. At this time, great difficulty was being experienced in maintaining even the former average of civilian enrollments, chiefly for economic reasons. About 80 technicians a year were being graduated from each of the schools that charged no tuition (Mayo Foundation and Walter Reed General Hospitals), but schools that charged tuition were having a difficult time securing students. Attempts to subsidize physical therapy schools, just as schools of nursing were subsidized, were not successful.

About 50 male students had been enrolled in physical therapy schools during 1942, but there was no automatic means of deferring them from Selective Service calls and each student had to be handled individually. The proposal that conscientious objectors be trained as physical therapy technicians was not accepted. Representatives of the Army and the Navy present at the 2 April 1942 meeting did not believe these men would fit into the Military Establishment.

The shortage of medical officers trained in the field of physical therapy persisted throughout the war and made it difficult, and sometimes impossible, to follow the regulation that all physical therapy sections be under the direction of officers with this qualification. The Subcommittee on Physical Therapy forwarded an offer to the Surgeons General of the Army and the Navy that free training would be provided at the Mayo Clinic and the Washington University and Cornell (Ithaca, N.Y.) Medical Schools for medical officers seeking qualification in physical therapy.

Later Developments

As the war continued, physical therapy technicians were particularly needed in neurosurgical centers and convalescent hospitals, to which patients were sent in increasing numbers. On 26 September 1944, the Director of the Hospital Division, Surgeon General's Office, called to the attention of the Directors of the Personnel and Training Divisions the need for additional technicians and suggested that both Wacs and enlisted men might be trained for this purpose or that qualified civilian personnel be hired (*6*). Civilian technicians had served at the beginning of the war, but were not employed as such later.

Part of the problem was solved by training groups of Wacs at various hospitals; Thomas E. England General Hospital (Atlantic City, N.J.), for instance, served as a training center for therapists in the Second Service Command. Most effective relief, however, was secured from the schools of physical therapy opened in January 1944, one at Percy Jones General Hospital, Battle Creek, Mich., and the other at Lawson General Hospital, Atlanta, Ga.

The School of Physical Therapy at Lawson General Hospital operated from 10 January 1944 through 1945. Entrance requirements, in addition to service in the Women's Army Corps, included 2 years of college, with majors in science. The accelerated curriculum consisted of 6 months of theory and supervised practice, followed by an apprenticeship of 3 months, with emphasis on practical application of the subjects taught in the formal schedule. Basic medical courses were taught by personnel of the medical and surgical hospital staff. Affiliation was secured with the Emory University School of Medicine, Atlanta, for instruction in applied anatomy. Each class paid a 2-day visit to the Warm Springs Foundation, Warm Springs, Ga., to observe the techniques practiced there.

The students had ample clinical material for practice. In 1942, Lawson General Hospital gave 93,075 physical therapy treatments, of which 31,532 were massage and 34,709 therapeutic exercises. From 1 January to 15 December 1945, it gave 220,825 treatments, 159,555 in the clinics and 68,170 on the wards. The modalities represented included electrotherapy (21,166), thermotherapy (20,000), massage (17,760), bandaging (18,994), thera-

peutic exercises (53,156), intermittent *venous occlusion* (1,300), and ultraviolet therapy (5,937).

The school was accredited for the training of physical therapy technicians by the Council on Medical Education, American Medical Association, as soon as it was in full operation. Of the 109 students enrolled in the six classes conducted, 91 had been commissioned by 31 January 1946. Two others completed the work but were refused commissions for physical reasons, and the remaining students, for one reason or another, did not complete the courses. Of the 91 commissioned graduates, 49 were assigned as apprentices to Lawson General Hospital. Lawson-trained technicians later served in 26 general and convalescent hospitals in the United States, and many others served overseas.

American National Red Cross Personnel

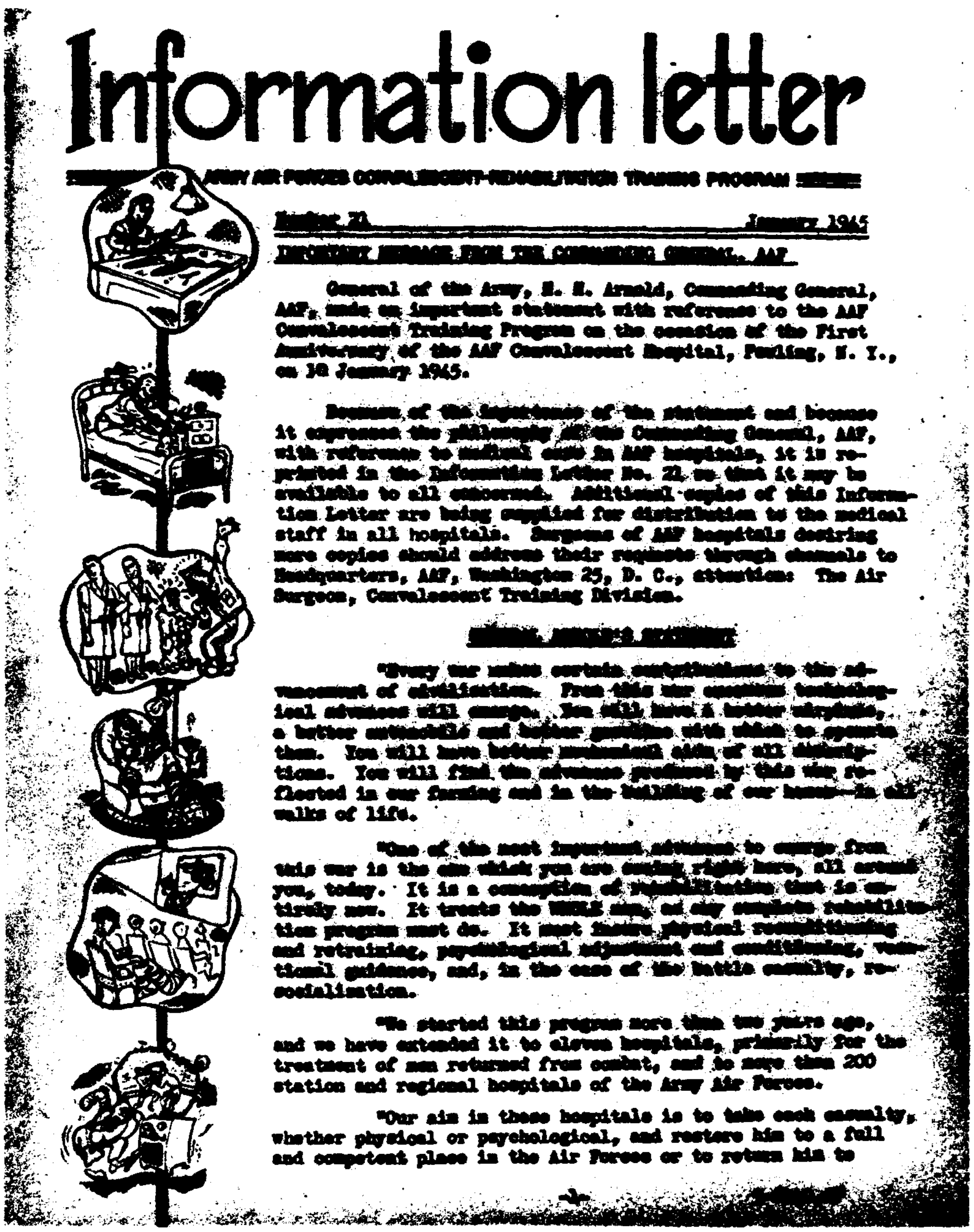
The American National Red Cross provided personnel assistance in Army hospitals to an extent not fully realized by the American public. It was organized and ready for action long before other nonprofessional activities in Army hospitals were organized. The Gray Ladies, the Blue Ladies (who did sewing and mending), the Canteen Corps, the Camp and Hospital Council, the Arts and Skills Corps, and, of course, nursing aides were all extremely useful.

At Lawson General Hospital, for example, in December 1944, 56 volunteers were working on the physical therapy and reconditioning services; they gave a total of 6,309 volunteer hours during the last 6 months of this year. In July 1944, this hospital had only two occupational therapists. Gray Ladies trained in this work began to visit the wards and were soon handling from 160 to 230 patients per month; during the July-December period, they worked with 325 patients. The Arts and Skills Corps began to work in November 1944 with 15 patients and with a second group of 10 patients the next month. They provided individual instruction on the wards and assisted in the Night Hobby Shop.

At Billings General Hospital (Indianapolis, Ind.), 97 Red Cross workers from the Arts and Skills Corps took entire charge of diversional occupational therapy, with a daily average of 130 patients, leaving the trained occupational therapists to concentrate on the functional aspects of the program.

Informational Material

At the 6 September 1941 meeting of the Subcommittee on Physical Therapy (*4*), the first draft was discussed of the manual on physical therapy that was later published in *War Medicine* for March 1942 (*7*) and copied from it in *The Army Medical Bulletin* for October 1942 (*8*). The material was intended merely as a guide for medical officers in the intelligent use of this modality. The subjects covered, in addition to certain nonorthopedic conditions, included chronic arthritis and rheumatoid conditions; traumatic synovitis; contusions and muscle strains; Volkmann's ischemia



Information letter

ARMY AIR FORCES CONVALESCENT-REHABILITATION TRAINING PROGRAM

Number 21 January 1945

IMPORTANT MESSAGE FROM THE COMMANDING GENERAL, AAF

General of the Army, H. H. Arnold, Commanding General, AAF, made an important statement with reference to the AAF Convalescent Training Program on the occasion of the First Anniversary of the AAF Convalescent Hospital, Pawling, N. Y., on 18 January 1945.

Because of the importance of the statement and because it expresses the philosophy of the Commanding General, AAF, with reference to medical care in AAF hospitals, it is reprinted in the Information Letter No. 21 so that it may be available to all concerned. Additional copies of this Information Letter are being supplied for distribution to the medical staff in all hospitals. Surgeons of AAF hospitals desiring more copies should address their requests through channels to Headquarters, AAF, Washington 25, D. C., attention: The Air Surgeon, Convalescent Training Division.

[illegible]

"Every war makes certain contributions to the advancement of civilization. From this war countless technological advances will emerge. You will have a better airplane, a better automobile and better gasoline with which to operate them. You will have better mechanical aids of all descriptions. You will find the advances produced by this war reflected in our farming and in the building of our homes—in all walks of life.

"One of the most important advances to emerge from this war is the one which you are seeing right here, all around you, today. It is a conception of rehabilitation that is entirely new. It treats the WHOLE man, as any complete rehabilitation program must do. It must insure physical reconditioning and retraining, psychological adjustment and conditioning, vocational guidance, and, in the case of the battle casualty, resocialization.

"We started this program more than two years ago, and we have extended it to eleven hospitals, primarily for the treatment of men returned from combat, and to more than 200 station and regional hospitals of the Army Air Forces.

"Our aim in these hospitals is to take each casualty, whether physical or psychological, and restore him to a full and competent place in the Air Forces or to return him to

-1-

FIGURE 118.—Page 1 of INFORMATION LETTER used in Army Air Forces rehabilitation program for January 1945 issue.

(contracture); bursitis; nonsuppurative tenosynovitis; fractures; peripheral nerve injuries; stiff joints; amputations; backache; painful feet; and traumatic cerebral spastic paralysis.

The subcommittee recommended that, until this manual became available, Krusen's "Physical Medicine" (Saunders, 1941) (*9*) be the text recommended for Army use.

War Department Technical Bulletin (TB MED) 137 was issued in January 1945 under the title "Physical Reconditioning for Bed and Ward Patients" (*10*). It incorporated the wartime experience and gave specific directions as to how the exercises recommended were to be conducted.

The *Information Letter* published monthly as part of the Army Air Forces Convalescent-Rehabilitation Training Program was first issued in April 1943 and was continued through April 1945 (fig. 118).

The Army Air Forces also published a "Handbook of Recovery" (Air Forces Manual No. 23) (*11*), which was prepared at the Institute for Crippled and Disabled, New York, N.Y., in 1944 (fig. 119). The pamphlet was addressed to patients, written colloquially, and illustrated with numerous instructional cartoons. It contained detailed exercises for all parts of the body, and a chart for the patient to keep track of his own progress in terms of range of motion and strength of muscles.

Army Service Forces Circular No. 73, issued on 11 March 1944 (*12*), contained the details of the reconditioning program.

CONFERENCES

Among the conferences on physical therapy and related fields held during the war were the following:

1. A 2-day conference was held at Lawson General Hospital on 28 and 29 April 1944, for designated officers from various general and station hospitals, to discuss all phases of reconditioning (*13*). More than 200 attended.
2. A 2-day conference was held at Schick General Hospital, Clinton, Iowa, on 21 and 22 March 1944, attended by representatives from the War Department General Staff; Headquarters, Army Service Forces; the Military District of Washington; the nine service commands; the Reconditioning Division of the Surgeon General's Office; the Army Special Services and Morale Services Divisions; a number of Army general hospitals; and the American National Red Cross.
3. A conference on physical therapy was held at Percy Jones General Hospital on 18 and 19 May 1945, under the supervision of the Consultant in Orthopedic Surgery, of the Surgeon General's Office. A similar conference was held at Gardiner General Hospital, Chicago, Ill., the following day. The 19 physical therapists who attended these conferences represented all the hospitals in which training courses were conducted and all the amputation centers, as well as a few other selected hospitals. Particular emphasis was placed upon physical therapy in amputees and on the value of therapeutic exercises in all types of thoracic and neurosurgical casualties.

Perhaps the most comprehensive and carefully planned reconditioning conference of the war was held at Halloran General Hospital, Staten Island, N.Y., on 24 April 1944, to demonstrate the management of classes IV and III (early) in the reconditioning program, and the following day at England General Hospital, to demonstrate the management of classes II and I (advanced) (*13*).

The demonstrations included physical therapy on the wards, medically supervised exercises on the wards, the ambulatory program on the wards for class III

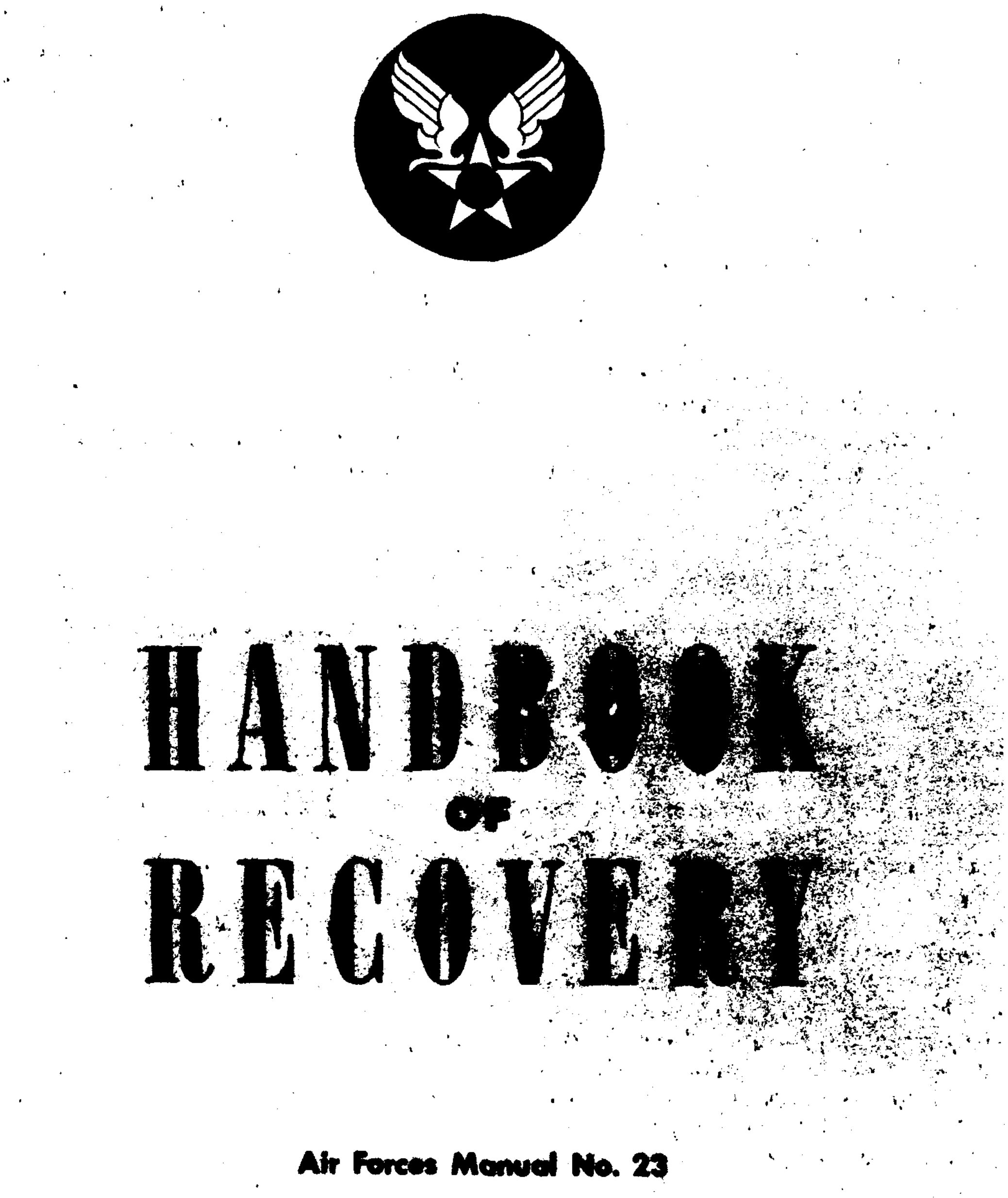


FIGURE 119.—Cover and first text page of Army Air Forces "Handbook of Recovery" (Air Forces Manual No. 23).

patients, the same program on the wards for class IV (nonambulatory) patients, and prescribed craft activities on the wards for class IV bed patients and class III patients restricted to the wards.

In all the demonstrations and discussions, emphasis was placed on the following points:

1. Medical supervision of the entire program.
2. Such coordination of physical therapy and occupational therapy by the medical adviser for the reconditioning program and the responsible medical officer that there was no duplication of effort.
3. The general participation at Halloran General Hospital in the voluntary phases of the program. When Col. Augustus Thorndike, MC, Director, Reconditioning Division, of the Surgeon General's Office, inquired, on a recent inspection trip, concerning the census, he was informed that of 1,176 patients, 1,170 were in the reconditioning program, and the other six were then too ill to participate.
4. A daily compulsory educational program, to which all class III patients were assigned. It consisted of training films; lectures on military subjects; talks by line officers, industrialists, war correspondents, and others; discussions of postwar job opportunities; and demonstrations of judo and jujitsu by Military Police.
5. A similar program for ward patients, embracing many of the same subjects. These patients were also taught airplane identification, first aid, nomenclature of weapons, self-defense, mathematics, languages, social sciences, and history.
6. Prescribed craft activities on the ward, conducted chiefly by Gray Ladies and the Arts and Skills Corps of the American National Red Cross but directed by the ward officer, who indicated the areas of the body that required activities and who also listed restrictions. Within 24 hours after admission, every patient had a craft activity prescribed for him.
7. Maintenance of strict military discipline in every department and activity. All patients who were ambulatory were marched to classes in military formation by the wardmaster. At the April 1944 conference, the patients in the rehabilitation conference staged a military review.

The program was highly flexible, as it had to be, with 58 wards to provide for. Since Halloran General Hospital was a debarkation-evacuation hospital as well as a general hospital, many patients remained only a few days, but any who were there long enough were immediately phased into the reconditioning program.

As soon as their medical status permitted, class III patients were moved to reconditioning barracks away from the hospital atmosphere. Barracks were inspected daily and formal inspection was held every Saturday. The patients wore uniforms, were subject to strict military discipline, but were, of course, carefully observed to be sure that they were also receiving the necessary medical attention. A typical day for this group consisted of reveille, fatigue details, calisthenics for 30 minutes, physical therapy, occupational therapy, a compulsory educational period, intensive muscle training, "dismounted" drill, and retreat. If a man neglected his duties, he was first warned, and then restricted to the post. Further disciplinary action was seldom necessary. The fact that wardmasters had to approve all passes enhanced their authority.

FACILITIES AND EQUIPMENT

In some hospitals, such as Brooke General Hospital (San Antonio, Tex.), the physical therapy and rehabilitation program had to be conducted in two sections, at a considerable distance from each other, which was wasteful of both personnel and equipment. In contrast was such a hospital as England General Hospital, which occupied both Haddon Hall and the Traymore Hotel. The beach and surf directly in front of the Traymore Hotel were used for swimming, sunbathing, and games. Physical reconditioning instructors assigned to beach duty supervised exercises and games and acted as lifeguards. This hotel had no swimming pool, but arrangements were made to use the pools at the Ambassador and President Hotels. A lawn connected with the Traymore Hotel was used for calisthenics, volleyball (three courts), horseshoes (four courts), paddle tennis, box hockey (six courts), badminton, basketball (two half courts), and a golf driving pit. Later, the Illinois Avenue Athletic Field, located a block from the hospital, was made available for other games. The excellently equipped remedial gymnasium at the Traymore Hotel was utilized the entire day, in 45-minute periods. Man-hours of use ranged from 1,968 in January 1945 to a peak of 3,382 hours in June.

The Atlantic City Country Club made its golf course and clubhouse available to the hospital patients every afternoon; they were transported back and forth by the Red Cross Motor Corps. This activity was participated in by 163 patients in July 1945 and by 725 in August. Some amputees played in the tournaments while they were still on crutches.

During the summer months, the patios of both Haddon Hall and the Traymore Hotel were used for gardening by interested patients. The plants and materials were furnished by the Garden Clubs of New Jersey through the American National Red Cross. The resulting gardens were very beautiful. During 1945, the Camp and Hospital Council of the American Red Cross provided power, hand, and bench tools for the craft shops to supplement supplies and materials furnished through regular channels. Picket fences and lawn chairs were made in the hospital workshops.

On Colonel Peterson's first inspection trips, late in 1943, numerous shortages of personnel, facilities, and equipment were observed, but it was surprising, given the will, the imagination, and the aggressive direction of those in charge of these programs how much was being achieved at some hospitals in spite of these deficiencies. Initial shortages were caused by the extension of the program to hospitals for which it had not been originally planned (p. 54). When the physical therapy and reconditioning program was in full operation, its equipment, though it might have been slow in procurement, left little to be desired and compared favorably with equipment in civilian institutions.

PHYSICAL THERAPY

In World War II, the former plan of waiting to institute physical therapy until the period of immobilization was ended found little favor. Instead, a program of active exercise was instituted as soon after injury as the patient's condition permitted, immediately after elective surgery, and, in anticipation of postoperative requirements, several days before operation. At some hospitals, it was a standing rule that every patient put into traction suspension be seen at once by the physical therapist. It was found, in spite of the original general impression to the contrary, that effective, systematic exercises could be carried out safely inside plaster casts or in the most complex traction. Results were surprisingly good when they were carried out regularly. A number of patients, for instance, were observed at Halloran General Hospital with perfect ankle, tarsal, and toe motion after weeks of immobilization, and without the use of foot pieces, simply because their surgeons had insisted that they move their feet many times daily.

Whenever possible, patients with similar orthopedic injuries and problems were assigned to the same wards. It was helpful to understand each other's difficulties, and the spirit of competition engendered in these circumstances was extremely healthful. Whenever it was available, special equipment was placed on these wards or was moved to them for the regular exercise periods.

The basis of treatment was to teach the patient to contract his muscles actively from the outset, regardless of the type of immobilization which his injury required. Passive stretching was replaced by active, vigorous, resisted joint motion as soon as necessary immobilization could be discontinued. Under this policy, good circulation was maintained, healing was stimulated, and stiffness of the joints, atrophy of muscles, and impaired coordination, which were formerly accepted as inevitable and which were often a factor in poor results, were reduced to a minimum.

Patients were given specific instructions:

1. Each muscle group must be forcefully contracted and exercised, just as though the joints were free to move.
2. Each muscle group must be systematically exercised in turn. Individual instructions were given concerning the location and function of the impaired muscle groups and how they were to be moved.
3. Routines of exercises varied (fig. 120). Perhaps the most effective was a period of vigorous exercise once a day, ranging from 10 to 30 minutes, depending upon circumstances, combined with a 5-minute period of exercise every daylight hour. Exercises were conducted under the supervision of the wardmaster. Sometimes the commands were called by one of the patients, while the wardmaster moved from patient to patient, making sure that the exercises were being properly carried out.
4. The psychologic state of the patients was extremely important. Part of the approach to the program was to teach them their responsibility for their own rehabilitation. Apathy and lethargy were not permitted. Great pains were taken to make clear to each patient exactly what injury he had sustained, why he was required to

FIGURE 120.—Modified calisthenics, under supervision of instructors, at Thomas M. England General Hospital, Atlantic City, N.J.

carry out monotonous, dull routines, and what the prognosis was with and without his cooperation. Part of the routine of recovery, in fact, was the development of the sort of physician-patient relation that is part of private practice and that was often unavoidably lacking in the Army.

5. Every effort was made to avoid any semblance of invalidism, physical or emotional. If the prognosis was poor, it was frankly discussed, at a carefully selected time, and the future was made to sound as optimistic as possible, but always within the limits of strict truthfulness.

6. Military discipline was insisted on. At the 2 June 1942 meeting of the Subcommittee on Orthopedic Surgery, National Research Council (*14*), Col. J. A. MacFarlane, RCAMC, Chief Medical Consultant, Canadian Armed Forces, stressed that the British experience had shown that the problems of rehabilitation were related chiefly to morale and discipline. The experience in U.S. Zone of Interior hospitals was the same. The results were best, and were achieved most promptly, when a high degree of military discipline was insisted on and the patients were required to observe all the military amenities and formalities. The patients had come to expect such discipline while on active service, and they were required to observe it in the reconditioning program.

FUNDAMENTALS OF REHABILITATION

There were four fundamental aspects of orthopedic rehabilitation; namely, repetition, resistance, reassurance (which has already been discussed), and sequence of exercises through three stages; namely, power, mobility, and coordination (*15*).

1. In the preservation or restoration of musculoarticular function, nothing proved of more importance than repetition of movement by the

patient himself. He was made to understand from the beginning that nothing took the place of his own repeated efforts.

In addition to its beneficial effects in muscular atrophy and joint stiffness, repetition prevented impaired coordination, which, it was learned by many painful experiences, was very much easier to prevent than to cure.

2. The wartime experience proved that heavy resistance exercises (p. 482) not only did no harm to weak muscles but were the fastest and most effective method of restoring them to normal dimensions and strength (*16*). Certain precautions, of course, were necessary: During heavily resisted contraction and relaxation, jerking was avoided, and contractions were smooth and slow. Heavy weight-lifting was built up gradually, and complete relaxation was practiced between lifts.

Minimal resistance free-swinging exercises were not employed until the muscles involved were sufficiently strong to protect the joints from the strains and sprains likely to occur from vigorous joint motion when muscles were weak.

Maintenance of good circulation in the joints was another important result of resistance exercises. During passive immobilization, the venous stasis that developed in the joints could lead ultimately to an edematous, inflexible joint capsule, extravasation of fibrin, atrophy of the articular cartilage, adhesions, and an immobile joint.

Elaborate apparatus was not necessary for resisted exercises. Ropes, pulleys, bags of weights, dumbbells, even the weight of the body itself were all adequate if they were supplemented by a fundamental knowledge of anatomic structures and a desire to achieve rehabilitation on the part of the medical officer and to become rehabilitated on the part of the patient.

3. In the process of rehabilitation, three stages, which were overlapping, were recognized:

a. The power stage, during which atrophied muscles were built up sufficiently to protect the joints which they controlled before wide ranges of joint motion and walking were permitted. At the end of convalescence, surprisingly heavy resistance was often possible. The injured extremity occasionally became stronger than the intact limb and its circumference larger. This was a distinct advantage in such injuries as rupture of the anterior crucial ligament.

b. The mobility stage, during which standard gymnastic procedures and equipment were used to good advantage. During this stage, care had to be taken that an eager patient did not go beyond the amount of exercise indicated. Muscle strength and endurance were kept just a little ahead of the increasing range of joint motion. Better function was derived from a joint with moderately limited mobility and strong activating muscles than from a fully mobile joint moved by weak muscles.

c. The coordination stage, in which emphasis was on restoration of precision of function. Occupational therapy was of the greatest value in this stage. At the earliest moment that a natural gait and posture were possible, the patient was persuaded and prodded into assuming them. Limping and malpostures were carefully observed, to prevent their becoming habits.

PSYCHOLOGIC FACTORS IN THE RECONDITIONING PROGRAM

Almost as soon as the United States entered World War II, a steady stream of patients with musculoskeletal symptoms were referred to the orthopedic wards and clinics (*17, 18*). In the beginning, before the facts of the situation were realized, these complaints were usually regarded as of organic origin, and intensive orthopedic therapy, including, in a few cases, surgery, was carried out during long periods of hospitalization. As experience increased, the psychogenic origin of many of these complaints became clear; in the last years of the war, the greatly reduced number of psychologic problems misdiagnosed as orthopedic conditions gave evidence of the greatly improved understanding of psychosomatic problems. Many orthopedic surgeons stated that, for the first time in their medical careers, they were "systematically treating patients with orthopedic disability in their entirety, as human beings, and not merely as animated skeletons." A few medical officers were, of course, so impressed with the new approach to orthopedic surgery that they were inclined to see a psychogenic basis for conditions that were clearly organic. Most military surgeons, however, followed the middle of the road.

Estimates of the incidence of psychogenic problems in orthopedic conditions varied. Capt. (later Maj.) James Vernon Luck, MC, reported that a survey of more than 500 hospitalized orthopedic patients showed that 11.1 percent had psychologic problems which were either the sole cause, or the most important contributing cause, of the musculoskeletal symptoms complained of (*17*). On the outpatient service of the same hospital, over the same period, the disability was predominantly psychologic in 25 percent. At Hoff General Hospital, Santa Barbara, Calif., Capt. (later Maj.) Edward W. Boland, MC, and Lt. Col. William P. Corr, MC, reported that "psychogenic rheumatism" was the most frequent cause of orthopedic symptoms in 450 consecutive cases in which the diagnosis was arthritis or some allied organic condition (*19*). Capt. (later Maj.) Earl Saxe, MC, reported that at Tilton General Hospital, Wrightstown, N.J., "functional muscular disability" comprised over half of the cases in which the admission diagnosis was "organic neurologic disease" (*20*).

On the basis of a detailed analysis of more than 1,000 cases in which psychogenic factors were the cause of musculoskeletal symptoms, Major Luck (*18*)[1] grouped these patients into three categories:

1. Those in whom no relevant organic lesion could be demonstrated.
2. Those in whom psychogenic problems were secondary to organic lesions.
3. Those in whom psychogenic problems perpetuated some of the physical symptoms of a healed organic lesion.

[1] Major Luck's other material (*18*) was collected from the hospital at Mitchel Field, Long Island, N. Y., and from a number of regional hospitals.

From a psychiatric standpoint, the disabilities in this series were divided into:

1. Conversion reactions.
2. Anxiety or tension states.
3. Elaborations (psychogenic elaboration of symptoms from an organic musculoskeletal lesion).

These types were more often seen in various combinations than in pure forms.

While no parts of the musculoskeletal system were exempt, sites most susceptible to becoming foci of neurotic symptoms included the low back, knees, feet, neck, and shoulders. A healed fracture or an operative scar served rather often as "the somatic focus into which the neurotic person channeled the expression of his emotional stresses."

Psychiatrists directed the treatment of patients with complex psychologic problems, but the orthopedic surgeon had to assume the responsibility for psychologic as well as orthopedic care in large numbers of these cases, particularly those with combined psychologic and organic musculoskeletal symptoms. In these cases, the abbreviated neuropsychiatric examination formulated by Dr. (later Brig. Gen., MC) William C. Menninger proved valuable both factually and in the saving of time (*21*).

Therapy included:

1. Evaluation of the patient and advice to him concerning the correction of environment conflicts.
2. Provision of insight into the character of existing psychologic symptoms, combined with an explanation of coexisting organic symptoms.
3. Identification and elimination of the underlying conflict when this was possible. When it was not, an attempt was made to control aggravating factors.
4. Administration of sedatives when chronic fatigue and insomnia were part of the picture.
5. Prescription of occupational therapy as indicated.

During treatment for true organic lesions, every effort was made to detect and correct bad psychologic trends and incipient neurotic reactions. Before elective treatment, particularly in such debatable conditions as internal derangements of the knee (p. 649), patients were carefully evaluated from the psychologic standpoint, and operation was not recommended if psychogenic factors were evident. If psychogenic factors had become evident only under prolonged mental and physical stress, the response to therapy was more hopeful than under the ordinary stresses of life. Those patients with neurotic musculoskeletal symptoms were urged to carry on and were persuaded that their work would do them no harm; what would do harm was their surrender to their symptoms, particularly trivial symptoms.

Obviously, men with the symptoms just described would not be benefited by surgical or physical therapy, particularly those who had no organic lesions to be benefited. As a matter of fact, they could be harmed, and a

FIGURE 121.—Patient using shoulder wheel to test and measure motion in right shoulder while instructor watches. Thomas M. England General Hospital, Atlantic City, N.J.

state of what Halliday termed "fixation invalidism" could be induced (*22*). This often happened early in the war, when hospitalization and treatment (*2*) of various kinds were continued for indefinite periods.

RECORDS AND TESTING

Keeping of careful records, frequently in the form of graphs, was an important part of the routine of rehabilitation. It was encouraging to both physician and patient, as well as to the physical therapist, to plot the growing improvement in respect to circumference, strength, and joint motion of the injured extremity.

The record system varied from hospital to hospital. At Fletcher General Hospital, Cambridge, Ohio, a card system was used, the cards being stamped by reconditioning personnel upon the completion of each period of activity. Patients whose cards were not so stamped were assumed not to have completed the assignment and were not allowed weekend passes. A number of hospitals employed this system.

At Mayo General Hospital, Galesburg, Ill., a vital energy test was carried out for class III patients each Friday afternoon; it included tests of the lung capacity, hand grip, and foot flexion.

At England General Hospital, a more elaborate series of tests was carried out periodically under the observation of medical officers and reconditioning instructors:

For patients with injuries of the upper extremity, it included a gymnastic testing program (situps, squat jumps, pushups, squats and bends, and 50-yard runs); wrist circumductor; shoulder wheel (fig. 121); elbow stretcher (overhead pulley); wrist supinator and pronator; hand dynamometer; pullups or, as an alternative, flexion and extension of the wrist.

For patients with injuries of the lower extremity, testing included dorsal and plantar flexion of the foot and ankle; riding a stationary bicycle; flexion of the leg; flexion of the thigh; extension of the leg; and hyperextension of the thigh.

At Oliver General Hospital, Augusta, Ga., the dramatic improvement in many patients in the reconditioning program stimulated the desire for photographic records. A special double-exposure technique was developed with a Speed Graphic camera which showed the angle of greatest extension and greatest flexion. The technique proved particularly valuable in such joints as the wrist and the phalangeal joints, in which it is difficult to measure the range of motion by goniometry. The photographic method was also useful in demonstrating false joint motion or motion from pseudoarthrosis.

REHABILITATION AND RECONDITIONING

Institution of Program

War Department Memorandum No. W40–6–43, dated 11 February 1943, entitled "Convalescence and Reconditioning in Hospitals" (*23*), directed the commanding generals of all service commands and all overseas commanders to institute programs of graded exercises, games, drills, indoctrination, and entertainment, to the end that the physical and emotional reconditioning of the disabled soldier might be rapid and complete. The program was to be carried out under individual medical supervision, with strict military discipline. Whenever it was practical, disabled soldiers were to be in uniform and housed apart from other soldiers. Exercise was to be prescribed on a scale graded to approach closely, but never to exceed, individual tolerance. "Morale is best restored by physical, mental and emotional activity quantitated on an ascending scale." Every effort was to be made to place each program in charge of a person with experience in physical education and with "a commanding personality."

Great care was taken to insure that ward and other personnel who conducted the exercises had been well trained, either on the job or formally.

At England General Hospital, only personnel with military occupational specialty 283 (Physical Reconditioning Instructor), who had completed the instructors' course at Camp Grant, Ill., or Fort Lewis, Wash., were allowed to conduct physical exercises. Such restrictions were not always practical, but, regardless of shortages, untrained personnel were not used for this purpose. At some hospitals, trained instructors were assisted in ward exercises by convalescent enlisted men, whose training for the work had been part of their rehabilitation. Four classes of training, ranging from IV to I, were recognized in the 11 February 1943 memorandum (*23*), and directions were given for the specific participation of each group of patients in the training program. In this memorandum, rather limited participation was required of the group IV trainees. As the original categories of training were developed from the standpoint of exercise and physical endurance, the patients in this group were given daily exercises in bed, under supervision, once or twice daily, or every hour, according to the routine used in the particular hospital. Group III patients were ambulatory, and the amount and kinds of exercises required of them were steadily increased as they progressed from category to category. Class I patients were expected to be able to walk 10 to 12 miles daily, under full pack.

The original assignment and the speed of progression were determined individually for each patient by the ward officer in consultation with the officer in charge of the reconditioning program.

Practical Considerations

The success of a rehabilitation (reconditioning) program depended upon a number of considerations, one of the most important being the careful preliminary evaluation of the patient. It was wise, when time and personnel permitted, to have every soldier returned from overseas or reporting to an orthopedic clinic—except those with acute trauma—interviewed by the personnel officer, who would determine his military vocational placement. The recommendations of this classification officer, supported by the medical officer's findings, should determine at once whether the man would meet the minimum standards of physical fitness for Army service. If he did not, his service could profitably be terminated at once. The classification and assignment of soldiers returned to duty from the rehabilitation program were always most satisfactory when there was close cooperation between the classification and assignment officers and the medical officers last concerned with their care.

Certain men could be—though they were not always—disposed of promptly. Those who complained of flat feet, internal derangements of the knee with persistent locking, and chronic low back conditions seldom did well in the reconditioning program, and their poor performance tended to disrupt it and demoralize those engaged in it. There was wisdom in the suggestion, which was never put into effect, that two separate programs

should be provided for convalescent casualties, one for those to be returned to duty and another for those to be separated from service.

Because of the notably slow convalescence of most orthopedic casualties, planning for rehabilitation had to be long-term, and that was explained to the patient without delay. He was told that, during this period of disability, he would be given whatever medical or surgical treatment was indicated. He would be, in effect, a student in a school in which, under military discipline, he would carry out a curriculum designed to improve both his mind and his body. Finally, he would be returned to duty at the earliest possible moment his physical condition would permit. If time were taken in the beginning to set these matters before the patients, they participated in the program with more cooperation and enthusiasm.

The reconditioning program was attended with many difficulties early in its implementation. On 10 December 1943, The Surgeon General addressed a letter to service command surgeons and commanding officers of named general hospitals (*24*), complaining that the program instituted on 11 February 1943 had been carried out to date with "much confusion, inertia, and lack of understanding." He wanted it put into effect at once and "diligently carried out" under the direct supervision of each commander and his administrative staff.

The difficulties in securing proper equipment for the program are described elsewhere (p. 54). Other troubles hampered many hospitals in the institution of the program. At Billings General Hospital, when the service was started in 1945, the lack of bedspace and the tremendous number of incoming patients made it necessary to relegate reconditioning activities to an abandoned, stove-heated barracks, some distance from the main hospital area. Isolation from the rest of the hospital caused administrative difficulties, and in the dead of winter, the program had to be discontinued temporarily, for only fully ambulatory patients could get to the shops for their assigned courses.

The hurricane that struck Atlantic City on 14 September 1944 (p. 880) did a great deal of damage to the newly opened physical therapy and reconditioning quarters in the basement of England General Hospital. A good deal of damaged equipment could be salvaged and repaired—much of it by the patients in the occupational section—and until the quarters could be reoccupied, the program was carried out on the first floor and in the basement of Haddon Hall.

At Mayo General Hospital, a Reconditioning Council was formed and operated most effectively. It consisted of the chiefs of services, the Chaplain, the Personal Affairs Officer, the Special Services Officer, and the American National Red Cross Director.

VOCATIONAL TRAINING

The transformation of a physically wrecked soldier into a useful, self-supporting citizen was not a chance happening. It was the result of careful

planning (*25*). It required the active cooperation of many members of a team, including the medical officer, who carried the principal responsibility; the physical therapist; the occupational therapist; the academic instructor; and the director of vocational rehabilitation, who assumed the greatest responsibility when maximum physical rehabilitation had been attained and the medical officer had become little more than an adviser (fig. 122).

After maximum medical care and reconditioning had been carried out, all planning and training centered around the man's permanent physical disability, and his future training was conducted in relation to it. Consideration was given to his educational status, intelligence quotient, adaptability, and prewar and present interests. The key to vocational training was the selection of a type of work which he could best carry out in the light of his mental status and his physical handicap. The most successful vocational rehabilitation program was one that was selected after all these variables had been evaluated. The value of occupational and vocational training depended in large part upon the enthusiasm and imagination of the personnel who administered it. Originally, because of shortages of trained personnel and for other reasons, the stress was on recreational therapy, which was little needed outside of neuropsychiatric sections. Later, as the program developed, as much emphasis as possible was placed on the functional aspects of the program.

Occupational therapy (fig. 123) was developed in general, regional, station, and convalescent hospitals, but because of shortages of trained personnel, no assignments were made to station and regional hospitals until October 1945 and February 1946, respectively. At a number of these hospitals, programs were developed informally before these dates, and some of them were excellent.

As part of the rehabilitation program, hospital work was assigned to patients to encourage physical activity. It included dusting, cleaning floors, pushing food carts, washing windows, and policing outside grounds. The patient then progressed to work in carpenter, machine, and plumbing shops, preferably for a specified number of hours each day. In the beginning, occupational therapy was designed principally for the development of muscles and stretching of joints. When the patient had progressed to working in special shops, where trades could be taught and his work would more nearly approach that of a skilled workman in industry, his aptitudes and skills were the basis of his assignments, preferably made, as already mentioned, by the classification officer from the personnel division of the post headquarters.

The excellent educational courses provided by the U.S. Armed Forces Institute had little appeal for some men whose educational level was low. In more propitious circumstances, educational reconditioning offered numerous opportunities for instruction and advancement. At Billings General Hospital, for instance, a volunteer corps of 40 teachers from Indianapolis provided individual bedside instruction, which was particularly useful for

THE RECOVERY ROAD

Designed to: 22 November 1944

Speed you on your Road to Recovery.
Provide worthwhile and profitable hours.
Prepare you for a brighter future.

Mimeographed by the Reconditioning Service of Lawson General Hospital.

1300 CLUB - Red Cross Building - 1300 hours today.

Today's program begins with a: "Sportlight"
"A Colored Cartoon".

Mr. Palmer, Special Assistant to the President of the United States, and the Honorable George Hamilton will speak about opportunities which will be offered to every soldier in the Housing Field when discharged. Ten million homes will be built after the war so that this field offers a worthwhile future.

This is a very important program - don't miss it!

- - -

MOTOR MECHANIC INSTRUCTION - OT #2 - 1900 - Tuesday and Friday evenings.

This excellent free instruction has been changed to Tuesday and Friday evenings in OT #2 at 1900 - 2100.

The Ford Motor Company has donated a Motor and Stand for this free instruction.

Excellent Ford instructors from Atlanta will be here to teach you this trade or give you knowledge of motor operation and repair. Visit OT #2 Friday evening at 1900 to enroll.

- - -

BELL BOMBER FREE TRAINING - OT #2 Nightly - 1900 Monday, Wednesday & Thursday
1915 Tuesday and Friday

If you will be leaving the service because of disability, you may take advantage - NO - of this free training Bell Bomber is offering every night in OT #2. They will train you regardless of disability. No obligation to you. Work in any plant.

Monday - Wednesday night, and Tuesday-Thursday night classes in:

BLUEPRINT READING
ELECTRIC CRIB
PRECISION INSTRUMENTS
METHODS TRAINING
RIVETING

A New Class begins Friday evenings in INSPECTION. This Friday evening class will be taught personally by Mr. Lewis, a disabled veteran of this war, who is at present, training Manager of Bell Aircraft Corporation

- - -

WEDNESDAY EVENING HOBBY SHOP

The Occupational Therapy Hobby Shop in OT #1 tonight from 1830 - 2100 will present the regular class in Pottery and Leatherwork. Expert instructors. The

(over)

FIGURE 122.—First page of bulletin for 22 November 1944, circulated among orthopedic casualties in rehabilitation program, Lawson General Hospital, Atlanta, Ga.

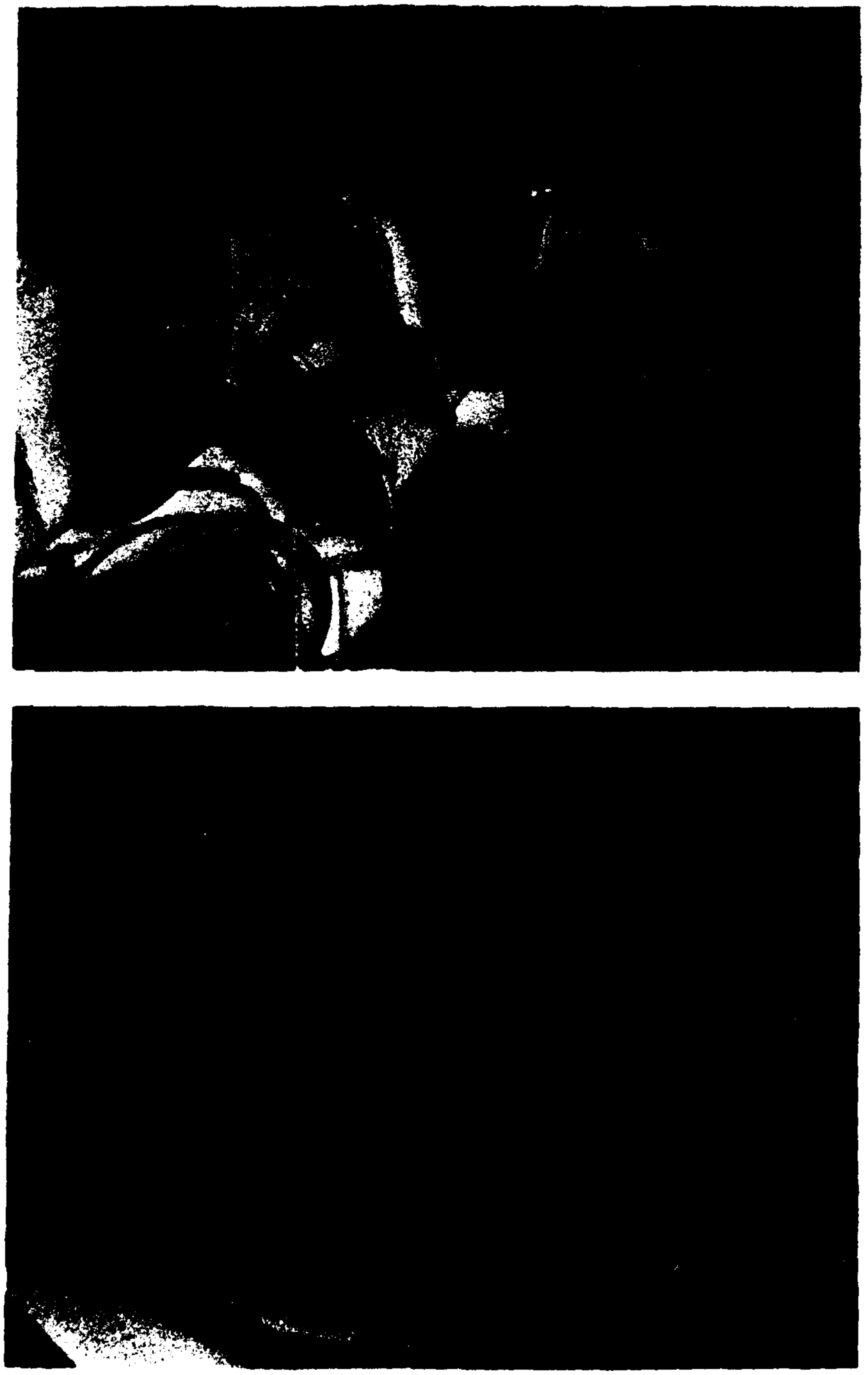


FIGURE 123.—Occupational training, Thomas M. England General Hospital, Atlantic City, N.J. (Top) Lessons in typing, with WAC sergeant as instructor. (Bottom) Lessons in draftsmanship, with sergeant as instructor.

patients who had enrolled in self-study courses. One group of men whose injuries prevented their return to their former civilian occupations enrolled in courses in accounting and made remarkable progress, chiefly because of the interest and enthusiasm engendered by the supplemental individual instruction they were receiving.

EVALUATION OF PROGRAM

The Consultant in Orthopedic Surgery, of the Surgeon General's Office, made certain interesting and significant observations concerning the rehabilitation program on his tours of inspection:

1. At some hospitals, such as Ashburn (McKinney, Tex.) and McCloskey (Temple, Tex.) General Hospitals, medical officers and physical therapy technicians showed a gratifying knowledge of their patients' needs and status. At a few other hospitals, where personnel was equally adequate and equipment was in equally good supply, the reverse was true. It was not strange that the results in the first mentioned hospitals were excellent while those in the second group ranged from fair to poor.

2. At Ashburn General Hospital, one of the three physical therapy technicians worked full time on the orthopedic wards. The value of this arrangement was evident in the good results secured in the function of the quadriceps and lower back muscles.

3. At a number of hospitals, though the orthopedic surgeon remained in charge of the program, convalescent line officers were trained to assist in it.

4. At some hospitals, the entire emphasis was on such measures as massage and heat, instead of on active exercises by the patient. In these institutions, an early, aggressive reconditioning program was discussed with all personnel involved.

5. The program at Fitzsimons General Hospital, Denver, Colo., was outstanding in all respects. Due attention was paid to correct immobilization, but muscle education and joint motion were constantly stressed. Group instruction was given daily, with special attention to quadriceps exercises. Ankle motion was practiced as indicated during the day, and the foot was well supported at night when the extremity was put up in suspension-traction. The chief emphasis at this hospital was on the return of men to duty. As might be expected in such a program, there was excellent liaison between the orthopedic surgery and physical therapy sections.

6. The program of therapeutic exercises developed at Gardiner General Hospital stressed the application of high resistance exercises to strengthen damaged or atrophic muscles (*2*). It received wide attention and was copied in other institutions.

As a result of these observations, Colonel Peterson sent the following recommendations to all hospitals:

1. Officers and other personnel must make themselves well acquainted with their patients' needs and progress.

2. Line officers being rehabilitated should be trained to assist in the reconditioning program.

3. Therapeutic exercises should take precedence over diversional activities.

4. Much greater emphasis should be placed on patients' participation in their own rehabilitation, particularly patients with disabilities of the quadriceps and lower back muscles.

5. Patients awaiting surgery should be well trained before operation in the exercises they will be required to perform after it.

6. Wherever the physical therapy program was still under direction of the medical section, it should be incorporated, as soon as possible, in the orthopedic section.

In retrospect, several other points in the physical therapy and reconditioning program impress one as of great importance in its success:

1. The best results were achieved when there was close contact between those in charge of the program and the orthopedic surgeons in charge of the injured trainees.

2. Originally, after major fractures, many casualties were left with enough stiffness and residual muscle atrophy to prevent their return to full duty. They had to be placed in some assignment requiring less physical effort from them or, in many instances, they had to be separated from service. The introduction of the reconditioning program eliminated numerous such problems, particularly in the training stage of the soldier's career.

3. The morale of orthopedic patients under treatment for long periods of time is often poor in civilian practice and was frequently a serious problem in the Army. With the improvement that occurred in his physical status in the course of the reconditioning program, there was usually a corresponding improvement in the soldier's morale.

4. One of the most valuable achievements of the reconditioning program was the restoration of the trainee's confidence in his own ability to do full military duty. The medical officer, watching the patient's progress, could evaluate his ability and use the evaluation as a basis for his disposition. This plan was far more efficient than sending him back to field duty, on the chance that he could hold up under it, and often having him returned to the hospital because his inability to do what was expected of him in the field organization was promptly demonstrated.

Medical officers were generally enthusiastic about the occupational and vocational program. Some of them predicted that occupational therapy departments would eventually be set up in all civilian hospitals as the result of wartime experiences. Most officers would undoubtedly return to civilian practice fully convinced that much of the posttraumatic and postoperative disability they had tolerated before the war was readily preventable.

WELCH CONVALESCENT HOSPITAL

During the period of operation of Welch Convalescent Hospital at Daytona Beach, Fla., from 16 May 1944 to 17 June 1946, 3,860 patients classified as orthopedic were admitted, treated, and disposed of by return to duty, transfer to general hospitals, or separation from service (*26*). Most of them had the usual problems of healing fractures, temporarily and partly ankylosed joints, slightly adherent tendons, and weak musculature.

Within a short time, it became apparent that the need for remedial gymnastics by these patients could not be met in the small gymnasium in the physical therapy section. Instead, there would be needed a special physical structure, as well as equipment and personnel in such amounts and numbers as to permit the complete separation of this activity from the remainder of the physical therapy section and its establishment as an independent section. It was possible to accomplish these objectives.

Treatment was at first entirely by individual prescription. When the results were evaluated after a sufficient period of time and were found to be satisfactory, patients with the same types of injuries were placed in the same housing areas, formed into groups of 10 to 30, and treated in these groups by the same treatment and the same types of activity. About 80 percent of all the patients fell into such groups (fig. 124). The remaining 20 percent required individual attention and instruction.

The mass-treatment plan was extremely successful from its inception, chiefly because of the close cooperation between orthopedic personnel and gymnastic instructors. There were no injuries or refractures in any of the groups, and nothing to indicate that control of the patients for remediable gymnastics by the gymnastic instructors was any less desirable—granted, of course, that their training was equally sound—than by the physical therapy technicians.

As the program developed, it became increasingly apparent, as it did in many similar programs, that the average orthopedic patient was capable of engaging in much more strenuous physical activity than had previously been permitted. When this accelerated plan was first put into effect, great care was taken to guard all participants against undue stress or strain that might overtax weak muscles, put excessive strain on ankylosed joints, or invite refracture of bones still in the early stages of healing. As experience accumulated, the degree of physical activity was greatly increased, often with difficulty because of the fear of many instructors that an unacceptable percentage of refractures would result. The incidence of refractures, however, remained consistently low, and careful analysis of each of the injuries led to the conclusion that the increased tempo of the program was not responsible for any of them. Most of them, in fact, occurred during off-duty activities or on furloughs or passes.

The increased physical activity in the program at this hospital was reflected in the rapidity with which weak, atrophied muscles were restored

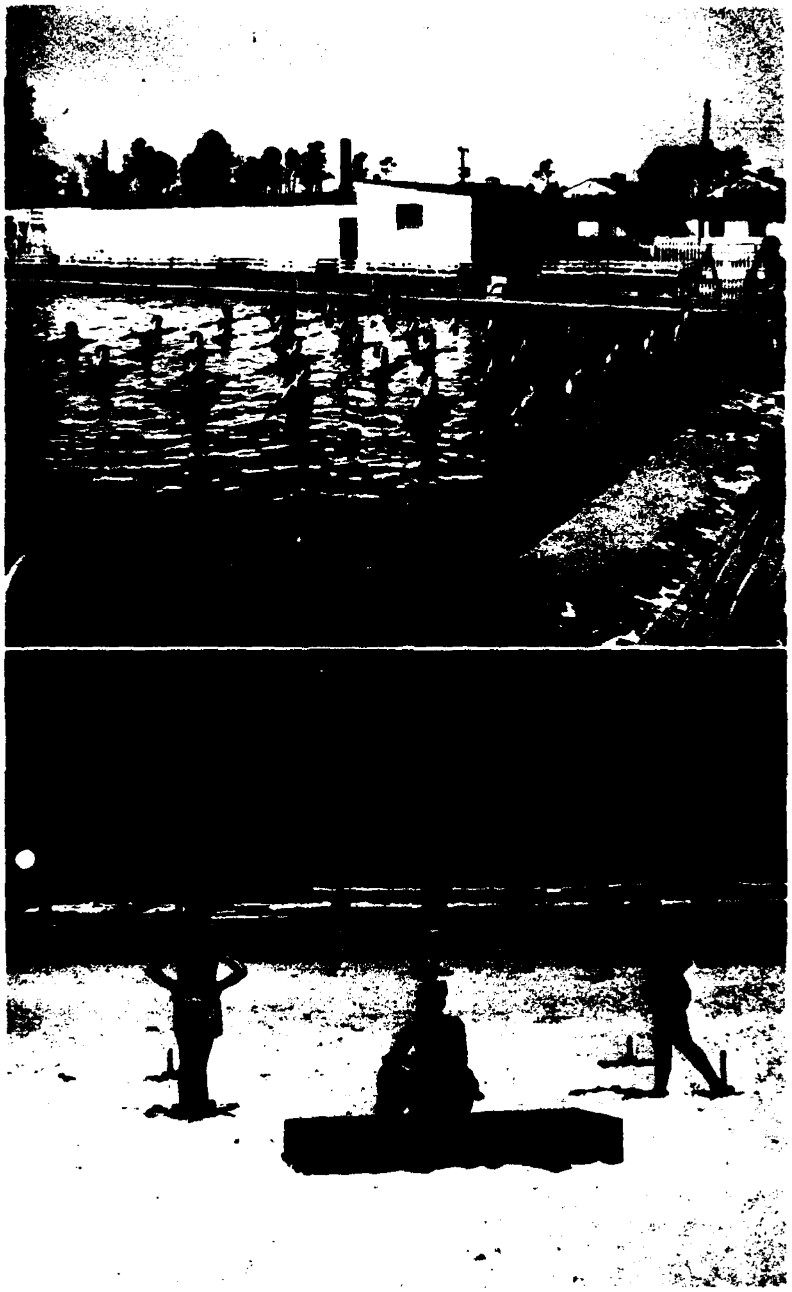


FIGURE 124.—Reconditioning program at Welch Convalescent Hospital, Daytona Beach, Fla. (Top) Group of 35 soldiers exercising as group in swimming pool under supervision of gymnastic instructor. This is an example of the mass treatment that proved so successful at this hospital. (Bottom) Convalescent soldiers pitching horseshoes and tossing basketballs on beach.

to normal size, strength, and tone. Even more striking was the ready mobilization of partly ankylosed joints. In fractures of the lower extremities, with residual partial ankylosis of the knee and ankle joints, muscle tone was regained and joint mobility was recovered at a rate not seen with more guarded forms of exercise.

Note.—Physical therapy and reconditioning of amputees are discussed in the section devoted to amputations (p. 929).

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Part V

REGIONAL FRACTURES: UPPER EXTREMITY

CHAPTER XVI

Injuries of the Shoulder and of the Head and Neck of the Humerus

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

Section I. Noncombat Injuries

FRACTURES OF THE CLAVICLE

Fractures of the clavicle, which were usually caused by direct violence, most often involved the middle third.[1] The proximal fragment was displaced upward, as the result of sternocleidomastoid pull, and the distal fragment was displaced downward, as the result of gravity and the downward pull of the pectoralis, the serratus anterior, and the latissimus dorsi.

That the treatment of fractures of the clavicle was far from satisfactory was evident in the multiple methods described for their management before World War II. They are difficult to deal with for two reasons, that they involve problems of both internal and external fixation of fragments and that they are so located that successful bone grafting for nonunion is hard to achieve. Early in the war, the impression was rather general that nonunion was uncommon, but the impression was incorrect; at the Army Air Forces conferences in 1943 (*1*), six instances were reported from a single hospital, all of which required bone grafting.

Accurate reduction was extremely important. The irregular bony surfaces and the bony spicules present in malunion or nonunion, although they were seldom associated with disability in civilian life, could be a constant source of annoyance, if not pain, to a soldier who had to carry a knapsack or a gun.

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[1] Unless otherwise indicated, most of the material in this chapter is derived from two sources:

1. A summary of the more important orthopedic information presented at the 12 Regional Fracture Orthopedic Conferences of the Army Air Forces held from 18 October through 12 November 1943 (*1*). The summary was prepared by Lt. Col. (later Col.) Alfred R. Shands, Jr., MC, Consultant in Orthopedic Surgery to the Army Air Forces and Chief of the Surgical Branch, Professional Division, Office of the Air Surgeon.

2. Studies on certain special orthopedic subjects, one of them lesions of the shoulder, prepared in 1945 but not published until 1948–49, by Maj. James Vernon Luck, USAF (MC), with the assistance of Maj. Hugh M. A. Smith, Jr., USAF (MC); Lt. Col. Henry B. Lacey, USAF (MC); and Colonel Shands (*2*). The material, which consists of 175 injuries, is hereafter termed "the Luck report."

Overall statistics are not available for injuries of the shoulder; the data in this chapter were personally collected and analyzed.

Nonsurgical measures.—Simple methods used in fractures of the clavicle included the Velpeau dressing; the Conwell dressing; the figure-of-eight dressing, achieved by either adhesive or plaster; the cross splint; and the T-splint.

For extensively comminuted and displaced fractures, in which reduction could not be maintained while the patient was ambulatory, recumbency and lateral traction to the upper arm, with the shoulders in abduction, were usually satisfactory. Four cases handled by this method were reported at the 1943 Army Air Forces conferences (*1*), at which there was also favorable discussion of the Kirk-Peterson splint.

Surgical management.—Open reduction of fractures of the clavicle was not often resorted to because results with this method were no better than results with more conservative methods. The use of metal plates and wires frequently caused irritation and delayed union; nonunion persisted until the foreign material was removed. Open reduction was seldom resorted to until other methods had failed.

At Ashford General Hospital, White Sulphur Springs, W. Va., the idea of partial resection of the clavicle for orthopedic disability grew out of the observation on the vascular surgery service that shoulder function was undisturbed after resection of various portions of this bone to facilitate approach to subclavian neurovascular structures (*3*). The orthopedic application of this technique was equally successful when union of a fracture failed to occur or malunion resulted. Within 3 weeks after resection of an inch or more of the proximal end of the clavicle, without postoperative splinting or fixation, the patient usually had normal range of motion in the extremity, and roentgenograms showed beginning regeneration of the bone (fig. 125).

One patient at Ashford General Hospital, for instance, with a fracture of the clavicle 1¼ inches lateral to the sternoclavicular joint, complained of pain on motion of the shoulder. At operation, the diagnosis was found to be malunion, not nonunion, as the roentgenograms had indicated. Both comfort and function were greatly improved by resection of the medial 2½ inches of the clavicle, including the sternal articulation. The same procedure produced equally good results in other patients with painful nonunion of the middle third of the clavicle.

FRACTURES OF THE SCAPULA

Fractures of the scapula (fig. 126), most of which were linear, were classified according to their location in the body, spine, acromial process, coracoid process, and neck and glenoid process. They were frequently comminuted. They resulted from direct trauma to the scapula itself or from indirect trauma to the lateral margin of the shoulder. When the shoulder was traumatized, the resulting injury was usually in the neck or the glenoid portion, and there was considerable deformity if it was severe.

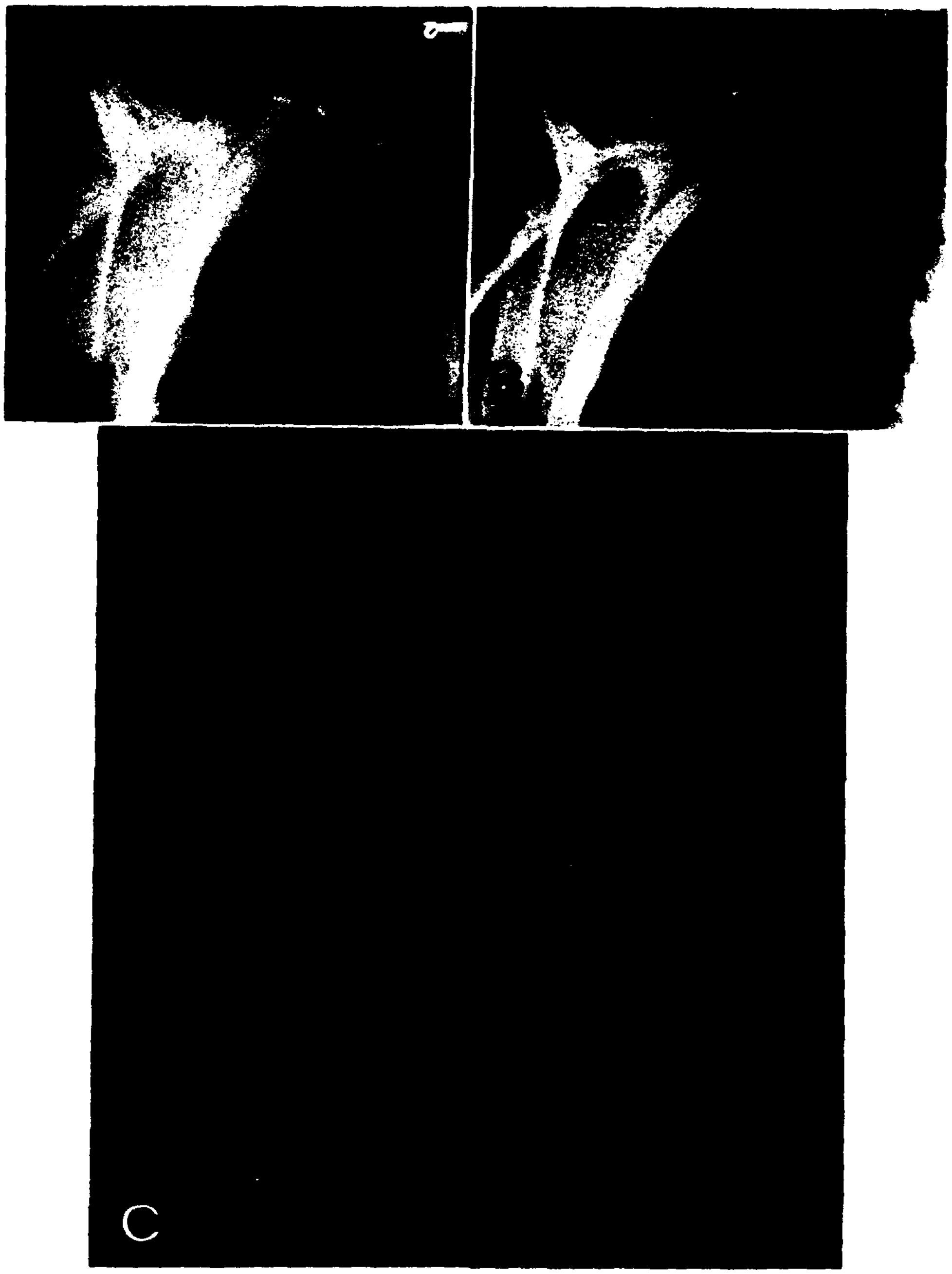

FIGURE 125.—Management of painful un-united fracture of clavicle by resection. A. Anteroposterior roentgenogram of right clavicle showing un-united fracture with ineffective wire suture in situ. B. Same, after resection of medial fragment and of fracture site. C. Photograph of patient 6 weeks after operation, showing range of elevation of both arms.

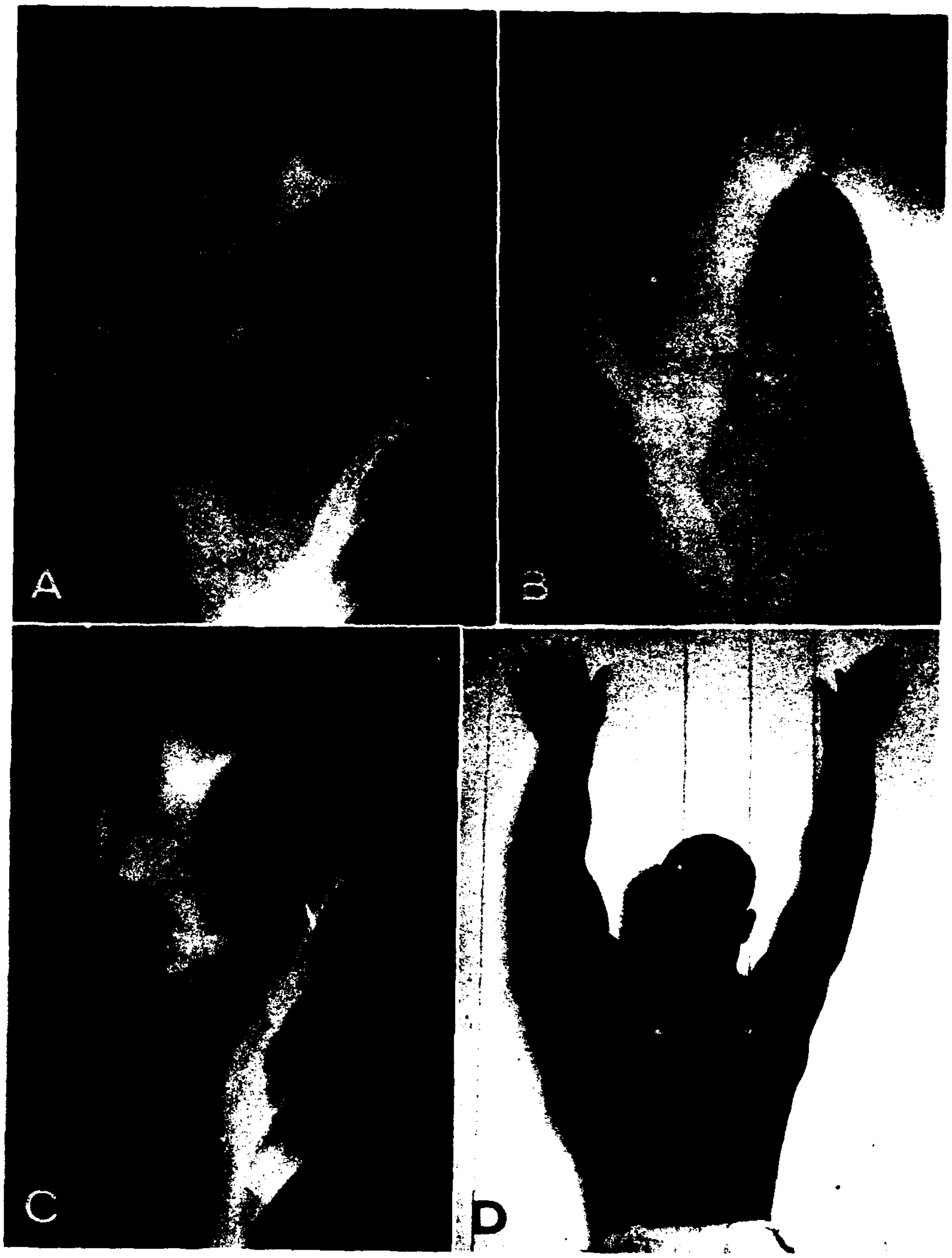

FIGURE 126.—Fractures of right and left scapulae in heavily muscled young soldier who was crushed under overturned jeep. A. Posteroanterior roentgenogram of left shoulder showing badly comminuted and displaced fracture of scapula. The injury was treated by traction, with two stainless steel wires placed in the vertebral border of the scapula and countertraction on the arm in the opposite direction. B. Posteroanterior roentgenogram of right shoulder showing crack through body of right scapula without displacement. No treatment was instituted. C. Posteroanterior roentgenogram of left shoulder showing fracture of scapula healed, but not completely reduced, after 5 weeks of traction. D. Photograph of soldier showing complete return of motion in both shoulders, 14 weeks after injury. He was returned to duty.

Simple fractures of the scapula were easily managed by any of the standard measures used in other injuries in this area. In severe fractures, with displacement, traction on the arm in abduction, with the patient recumbent, was necessary to restore the glenoid process to its normal position. Weights of 12 to 15 pounds were sometimes used for a month. If the fracture was impacted, manipulation to break up the impaction might be required before traction was applied.

Fractures of the acromial process caused remarkably little disability. Even when they were un-united, the patient usually had an uninterrupted range of motion and had no pain. If nonunion seemed to interfere with scapulohumeral function, further stability and improved function could be secured by bridging the gap with a bone graft. This was necessary in only one of six such cases observed at Vaughan General Hospital, Hines, Ill.

In fractures of the coracoid process, the pull of the short head of the biceps, the brachialis, and the pectoralis minor muscles tended to displace the coracoid process away from the base. The muscle pull could be relieved and the fragments restored to normal position by using a felt pad for counterpressure over the process and pulling the shoulder forward with the forearm flexed.

Good results usually followed these measures unless there was extensive involvement of the glenoid articulation in the injury. In such cases, traumatic arthritis or periarthritis was a frequent sequel and the end result was a painful shoulder with limited motion.[2]

FRACTURES OF THE HEAD AND NECK OF THE HUMERUS

General Considerations

Fractures of the neck of the humerus were not usually associated with deformity. When a deformity was present, however, it was highly typical: The proximal fragment was abducted by the supraspinatus muscles, with some external rotation, while the distal fragment was pulled up under the coracoid process by the deltoid, the triceps, and the coracobrachialis muscles. The internal displacement that was part of the picture resulted from the tension of the pectoralis major, latissimus dorsi, and teres major muscles.

From the standpoint of treatment and end results, it made little difference whether the fracture was in the cancellous bone of the anatomic neck or the compact bone of the surgical neck.

The incidence of noncombat fractures of the head and anatomic neck of the humerus was not large in World War II. Shattering fractures of the cancellous head of the humerus by crushing injuries are not apt to occur in persons of the age of soldiers but rather in older persons, with

[2] The special shoulder injuries sustained by paratroopers are discussed under that heading (p. 188).

decalcification of the bones. The principal fracture encountered in this area above the surgical neck of the humerus was avulsion of the greater tuberosity, with or without dislocation of the shoulder joint.

Management

In the management of associated fractures of the shoulder and the head or neck of the humerus, some surgeons preferred the shoulder spica, though they were willing to use the hanging cast in selected cases in fixed installations, in which constant supervision of the patient was possible. Others preferred reduction under anesthesia, followed by a hanging cast, for fractures of the neck of the humerus. If good reduction was effected originally, the rough edges of the fragments tended to maintain it. Muscle spasm was eliminated by the continuous traction provided by the cast, which was worn until there was satisfactory roentgenologic evidence of union.

The forearm was held across the chest by a sling, which was shortened if the end of the distal fragment was displaced forward or inward and was lengthened if it was displaced backward and outward. A pad applied to the inner margin of the cast at the upper end tended to prevent slippage. Care had to be taken to prevent rotation deformity, which occurred readily in these fractures and which could be extremely crippling.

The patient was instructed how to handle his arm: He was to let it hang from the shoulder when he was upright and to be careful about resting his elbow when he was seated. Active motion was begun a day or two after injury. The patient leaned forward, so that his arm hung free, and swung it back and forth across his body. As pain and tenderness subsided, rotation exercises were begun and were carried out in a gradually increasing range.

If satisfactory reduction could not be accomplished by the method just described, then the patient had to be kept recumbent, in skin or skeletal traction.

Unless the fracture of the humerus was in its long axis, either in or just below the head, traction-countertraction was a satisfactory method of reducing it. If the fracture was impacted, as it was only occasionally in men of Army age, and if there was no displacement, friction and the locking force of the head against the inferior margin of the glenoid process were likely to produce displacement. When this occurred, the head remained in the axilla and the fractured portion of the shaft came to lie in the glenoid fossa. It was sometimes possible to reduce the head by digital pressure while traction was exerted by an assistant against the countertraction of a sheet over the supraclavicular region. When this method was used, quick action was necessary because, if the manipulation was delayed, edema might make control of the head difficult.

If the shorter fragment was found displaced at the original examination, the orthopedic surgeon was confronted with a problem that taxed his

manipulative ability. The fractured surface of the head usually presented laterally, or superiorly and laterally. In these circumstances, it was easy to reduce the dislocation with the head of the humerus upside down. To prevent such a mistake, the arm had to be widely abducted, to bring the long axis of the distal fragment into line with the same axis of the short proximal fragment.

In some displaced fractures of the head of the humerus, open reduction and internal fixation were necessary.

Fractures of the tuberosities of the humerus ordinarily presented no problems. If the greater tuberosity was displaced, correction could usually be achieved by a position of 90 degrees of abduction and 180 degrees of external rotation maintained for about 3 days. Daily physical therapy and passive motion prevented permanent disability. If the lesser tuberosity was displaced, the arm was positioned across the chest, to relieve the pull of the subscapularis, and was held in place with an adhesive dressing.

Avulsion fractures also presented few problems, especially if the avulsed fragment maintained its periosteal attachment. After reduction of the fracture, the fragment lay in normal position and all that was required was immobilization in adduction. When the fragment was small, however, it was frequently detached and postreduction roentgenograms usually revealed it to be displaced by retraction of the supraspinatus. It was then necessary to immobilize the arm in the abducted, externally rotated, and forward flexed position. The cast or splint had to be applied very expertly to prevent redislocation of the fragment.

STERNOCLAVICULAR DISLOCATIONS

A sternoclavicular dislocation usually resulted from the application of force to the shoulder in such a fashion that anterior dislocation of the clavicle followed. Direct force applied at the inner end of the clavicle sometimes displaced the bone into the chest, but, because of the position of the first rib, the dislocation was usually anterior.

The application of adhesive strapping, with a pad over the proximal end of the clavicle and with similar strapping of the intact side, was a simple, frequently effective method of treatment. A circular strapping was applied about the entire chest, and the affected arm was supported by a sling.

Another method was the insertion of a short Kirschner wire through the sternum into the clavicle. This method was reserved for exceptional cases. It was not free from risk, and whenever it was used, care had to be taken that the wire did not migrate inwardly.

Dislocation of the sternal end of the clavicle was produced by the same forces that dislocated the lateral end. This type of dislocation was comparatively uncommon. Recurrent or chronic dislocation of the clavicle was

not so disabling at the sternal end as at the lateral end, and often the only complaint was cosmetic and concerned the bony prominence.

ACROMIOCLAVICULAR AND CORACOCLAVICULAR DISLOCATIONS

General Considerations

An acromioclavicular dislocation was the result of the application of force to the rounded deltoid area (the so-called point of the shoulder) with its direction toward the midline. The trauma produced by compression of the affected area was followed by buckling at the articulation. The supporting structures were torn, and, if the force was sufficiently great, the coracoclavicular ligaments were ruptured. All coracoclavicular separations were also acromioclavicular, but all acromioclavicular separations were not associated with rupture of the coracoclavicular ligaments. Rupture of these ligaments was always serious and practically always resulted in some permanent disability.

Once the coracoclavicular ligaments were damaged, muscular pull combined with gravity produced a characteristic deformity, with the distal end of the clavicle riding upward and forward. The extent of ligamentous damage determined the amount of displacement of the point of the shoulder. If the conoid and trapezoid ligaments remained intact, the dislocation was incomplete and the injury far less severe than when all the supporting and limiting ligaments were ruptured.

Incomplete acromioclavicular dislocations, even when not successfully reduced, often resulted in a painless joint and completely normal shoulder function. Complete dislocations, with associated tears of the coracoclavicular ligaments, also sometimes resulted in good, painless function if left unreduced, though the deformity was obvious. Finally, considerable stability not infrequently followed calcification of the coracoclavicular ligaments. As a rule, however, there was some residual discomfort and soreness if acromioclavicular dislocations were not reduced.

Management

There were a number of ways of managing these dislocations:

1. Application of a plaster dressing, usually in the form of a hanging body cast, with a shelf for support of the elbow and forearm.

2. Incorporation in the cast of a 3-inch elastic bandage in such a manner that the weight of the cast, acting through the bandage, exerted a constant downward force on the outer end of the clavicle.

3. Application over the outer end of the clavicle of a 12-inch plaster girdle incorporating a wide cotton webbing strap.

4. The application around the outer edge of the clavicle and the olecranon of a circular dressing made of adhesive plaster and provided with buckles. A 2-inch webbing strap could also be used. It was reported at the 1943 Army Air Forces conferences (*1*) that Thorndike of Boston, Mass., had used this method with good results in 138 acromioclavicular dislocations.

In fractures of the coracoid process, the pull of the short head of the biceps, the brachialis, and the pectoralis minor could be relieved and the fragments restored to their normal position by using a felt pad for counter-pressure over the process and pulling the shoulder forward with the forearm flexed.

Wires applied in various ways, including fastening the clavicle down to the coracoid process, was a fairly popular procedure. Fascia lata could be substituted for wires. Excision of the outer end of the clavicle by the Mumford technique also gave good results in many cases.

Coracoclavicular dislocations were handled routinely by some type of open reduction with repair of the torn ligaments. It was the only possible procedure, in fact, when the dislocation was complete and there was total rupture of the ligaments. After reduction, the ligaments were fixed by the Bosworth screw, which was left in place for 10 to 12 weeks.

Removal of the distal 2 centimeters of the clavicle was also practiced in acromioclavicular subluxations and dislocations at Ashford General Hospital; relief of pain was achieved without weakening of the shoulder. One patient, treated by fascial reconstruction of the torn ligaments as well as replacement of the clavicle because of extreme displacement of bony structures, had no perceptible anatomic improvement but was entirely relieved of his symptoms.

ACUTE (FRESH, PRIMARY) DISLOCATIONS OF THE SHOULDER

General Considerations

In military as in civilian practice, the important consideration in the management of injuries of the shoulder, arm, elbow, and forearm is that the purpose of the upper extremity is to serve the tactile and prehensile function of the hands and fingers. These structures are the essential and vital parts of the extremity. Their function is of primary importance. If there is no nerve damage, and if the hand is not injured, or is not injured beyond repair, its normal function can be retained or at least approximated. If that is possible, then loss of function in the shoulder or the elbow joint, regrettable as it is, does not constitute a major disability, and the casualty can continue an active and remunerative civilian life though he is unfitted for military duty.

It was on these general principles that all injuries of the upper extremity were managed in all military hospitals in World War II.

Early, accurate diagnosis of dislocations of the shoulder permitted simple, correct treatment that usually gave good results. Overlooked diagnoses, delay, and inadequate or incorrect treatment could result in permanent disability. The shorter the lapse of time between the injury and the examination of the patient and the institution of treatment, the less were the difficulties encountered and the prompter was the patient's return to duty.

Primary dislocations of the shoulder were usually cared for in station hospitals, and many operations for old chronic dislocations were also done at this level of medical care. Patients with postsurgery recurrences were usually assigned to general hospitals. As a rule, fresh dislocations of the shoulder were handled in general hospitals only when the hospital was on or near a training camp.

Pathologic Process

The anatomic structure of the shoulder joint and its resulting instability explain its ready susceptibility to injury. Dislocations in the Army, as in civilian life, occurred by any one of the following mechanisms, operating singly or in combination:

1. The man, falling backward, caught himself on his hands, which were outstretched behind his body. The force to which one extremity, or both, was subjected thus drove the head of the humerus forward and tore the glenoid labrum.
2. When the arm was abducted 90 degrees or more and externally rotated, any force directed against its external aspect drove it backward, with a resulting anterior dislocation, and, usually, an associated tear of the glenoid labrum.
3. Some bizarre or unusual situation might be responsible for the injury. Among unusual mechanisms observed during World War II was a rotary dislocation in which the head of the humerus had apparently turned completely around in the glenoid fossa without ever emerging from it. It was extremely difficult to visualize the dislocation by roentgenograms.

The three most frequent pathologic changes in dislocation of the shoulder were, in order of importance, rupture of the glenoid labrum from its attachment to the anterior margin of the glenoid; a posterosuperior defect in the head of the humerus; and denudation, erosion, eburnation, or fracture of the posterior lip of the glenoid. According to Bankart (*4*), whose work was later supplemented by that of Bost and Inman (*5*), the essential lesion in a dislocation of the shoulder was the first of these changes; that is, rupture of the glenoid labrum from its attachment to the anterior glenoid margin. The anterior capsule might tear at its attachment to the glenoid labrum, might be avulsed with the labrum, or might tear independently of the labrum at any point between the margin of the glenoid and the anchorage of the capsule in the head of the humerus. When the tear

was at the glenoid, the capsule seldom separated so extensively that, when the head dislocated, it became extra-articular. On the contrary, the anterior capsule, including the superior and the inferior glenoid-humeral ligaments, became so relaxed that the head of the humerus could slide over the glenoid rim. In perhaps two-thirds of all injuries of the shoulder, a notch created by the rather sharp edge of the glenoid was evident in the posterosuperior aspect of the head of the humerus. This notch varied from a localized area of cystic change to a deep defect.

Changes in the glenoid rim after the injury varied in magnitude. According to Bankart, they might be limited to detachment of the labrum or might include stripping of the capsule and periosteum from the anteroinferior portion of the rim and the neck of the scapula. The fibrocartilaginous glenoid labrum might become degenerated or might be frayed or torn across, leaving a free end of varying length loose in the joint or entirely absent. The rim might show a chip fracture or might be smooth, rounded, and eburnated, with no fibrous or periosteal tissue left attached to the involved area. The capsule and periosteum might be stripped from the neck of the scapula for a short distance, leaving a space which in time became lined with synovial membrane.

Associated Lesions

Fresh dislocations of the shoulder joint were often associated with other lesions, including soft tissue injuries, nerve involvement, fractures of the components of the joint, and fractures of the head and neck of the humerus and of the greater tuberosity.

Soft-tissue injuries.—Injuries of the supraspinatus tendon were uncommon, but could give rise to serious disabilities. The diagnosis depended upon tenderness over the attachment of the tendon on the tip of the greater tuberosity of the humerus and characteristic powerlessness when abduction of the arm was attempted. Inability to perform the first 15 degrees of abduction was considered typical by some orthopedic surgeons. Others emphasized weak abduction, from 50 to 70 degrees, with further attempts producing no more than a shrug of the shoulder. In chronic cases of tendon rupture, a small mass was sometimes present in the involved area and could occasionally be demonstrated by roentgenograms.

Rupture of the supraspinatus tendon was often confused with bursitis; if bursal adhesions were present, the arm could not be abducted passively, even when force was used to the limit of prudence. Another condition which produced similar limitation of motion was tendinitis calcarea, which was frequently symptomatic after trauma. If the tendon was ruptured, passive abduction beyond the limited active range was painless, whereas in tendinitis calcarea, it was painful.

If the injury of the tendon was recognized early, some surgeons preferred to correct it by immediate surgery. Others thought open operation

unnecessary in view of the good results that could be obtained with immobilization and physical therapy. If roentgenologic examination showed calcium deposits in the tendon, local infiltration of 10 to 20 cubic centimeters of 1-percent Novocain (procaine hydrochloride) was the basic treatment.

Whatever method was used, treatment was long-term and required transfer of the patient from a station hospital to a general hospital.

Rupture of the long head of the biceps, which was also not frequent, was much less disabling than rupture of the supraspinatus tendon. Diagnosis was based on the characteristic deformity; that is, a bicipital bulge or fullness. Early suture was desirable but was not essential to cure.

Nerve involvement.—Associated nerve injuries complicated perhaps 25 percent of all dislocations of the shoulder. The damage, which chiefly involved the brachial plexus and most particularly the circumflex nerve, ranged from transitory sensory manifestations to permanent paralysis of various muscle groups. Stretching injuries involving the long thoracic nerve, with paralysis of the serratus anterior muscle, produced the so-called wing scapula, in which the vertebral border of the scapula projected outward and the resulting deformity was associated with weakness of the shoulder.

When treatment of nerve injuries was delayed because of failure of diagnosis, the prognosis was likely to be poor. On the other hand, the recommendation made at one of the 1943 Army Air Forces conferences (*1*), that if the axillary nerve had been damaged, immediate suture should be done, was not realistic. Results were just as good if surgery was deferred until there was clear-cut evidence that nerve function would not return in natural course.

If the long thoracic nerve was permanently damaged, internal fixation of the scapula was necessary. Surgical measures, however, were of questionable merit. They included the creation of fascial slings between the spine and the scapula or between the scapula and voluntary muscles such as the pectoralis major, in an attempt to restore function to the serratus magnus.

The management of nerve injuries associated with orthopedic injuries is discussed more fully in the two volumes in this historical series concerned with neurosurgery (*6, 7*).

Diagnostic Considerations

Dislocations of the shoulder, particularly early in the war, were sometimes examined only perfunctorily, regarded as sprains, and treated accordingly. This was unfortunate. Even when these injuries were correctly treated, they were potentially serious from the military as well as the personal standpoint, as indicated by the time lost from duty from them.

It was particularly important, if the dislocation was associated with a fracture of the upper end of the humerus, that the fracture be recognized before any energetic manipulations were undertaken to reduce the dislocation.

History.—All complaints referable to the shoulder required questioning the patient carefully, not only about possible recent injuries but also about any past injuries.

Clinical examination.—The next step in the diagnostic routine was inspection and palpation, to detect deformity and crepitus. The examination was made with the patient stripped to the waist, so that the shoulders could be examined comparatively. Diagnosis by physical means was usually possible because of the superficial location of the involved structures. On the other hand, while flattening of the deltoid and projection of the elbow from the side were characteristic of subcoracoid dislocations, these phenomena gave no indication of the possible presence of an associated fracture of the greater tuberosity, which was present in about a quarter of all dislocations.

Careful observation of the range of motion and its limitations was part of the physical examination.

Roentgenologic examination.—Roentgenologic examination of the injured shoulder was valuable for the record as well as for diagnostic reasons. It was necessary to detect or eliminate fractures, the majority of which were of the avulsion type and involved various portions of the greater tuberosity. They might also be transverse, in the subcapital region, and without displacement until reduction of the luxation was attempted. It was in this latter group that prompt roentgenologic examination was of great importance.

Anteroposterior and lateral projections were made routinely. The anteroposterior film was made with the arm in internal, and then in external, rotation; one position often showed up an abnormality not seen in the other. The lateral film was made with the arm in abduction, the film on top of the shoulder, and the tube in the axilla. In reading the films, it had to be borne in mind that the characteristic deformity of dislocation might not be evident with the patient supine.

Management

More than one military orthopedic surgeon noted ruefully that reduction of a fresh dislocation of the shoulder was usually technically simple to achieve but very difficult to maintain. No single method was used exclusively, probably because no single method was found wholly satisfactory.

Some surgeons preferred to reduce the dislocation under general anesthesia. Others preferred the installation of Novocain directly into the

joint. Still others preferred a prereduction injection of morphine, which was given by vein if the need was urgent.

The procedures employed included:

1. The Kocher technique, which was used infrequently early in the war and later was almost entirely abandoned.
2. The three-sheet method. One sheet was applied around the chest high in the axilla, to provide a pull across the chest. The second was applied around the forearm, with the elbow flexed, so that the arm could be pulled down. The third was applied high on the upper arm, to pull it outward from the chest wall.
3. Pulling the extremity straight out in abduction, with countertraction provided by the surgeon's foot against the chest wall. In a variant of this technique, countertraction was provided by an assistant, who pulled on a folded sheet placed in the axilla and across the chest wall. Gentle traction was applied steadily to the abducted area for 2 to 3 minutes.

Splints used to keep the dislocated shoulder immobilized after reduction had a number of disadvantages. Adhesive taping, although easy to apply, did not hold its position well and had to be reapplied frequently. Plaster in itself was heavy, bulky, and uncomfortable, and discouraged early ambulation. Some orthopedic surgeons objected to hanging plaster casts in dislocations of the shoulder for two reasons, (1) that they were less comfortable than spicas and (2) that they resulted in an increased fixation of the shoulder joint that was difficult to overcome. Spicas were more difficult to apply than hanging casts. The shoulder girdle is such a mobile structure that, even in the hands of an experienced orthopedic surgeon, the relation between humerus and scapula was often difficult to determine, and the position in which the shoulder was put up was not always correct.

Surgery was practically never indicated after the first episode of dislocation.

RECURRENT (CHRONIC) DISLOCATIONS

General Considerations

According to Army regulations, men with recurrent dislocations of the shoulder were not to be considered as eligible for service (*8*), but large numbers, nonetheless, were inducted. Of the 175 recurrent dislocations in the Luck series, only 45 were line-of-duty-yes injuries (*2*). The other 130 injuries existed prior to induction. A recurrent dislocation was not a major problem, at least in the pathologic sense, and it carried no lethal implications, but in view of the man-days lost thereby, the effort required for its management by orthopedic surgeons, other medical officers, and related personnel, and the futility of so much of the expenditure, it really was a frustrating entity.

Recurrent dislocations that became manifest during training presented administrative as well as clinical problems. Some men were inclined to minimize their disability. Others tried to magnify it. The original dislocation sometimes became recurrent promptly because it had been improperly reduced and immobilized, or because immobilization had been too brief. Finally, in addition to the clinical indications for its performance, operation frequently depended upon whether or not the injury was preexistent or was really service connected.

In the 175 dislocations in the Luck series, the diagnosis in 94 was based entirely on the patient's own story of recurrences. In 22 of these 94 cases, no physicians had seen the patients, who had reduced their own presumed dislocations. When they were questioned about previous professional treatment, many reported that it had consisted only of reduction and the use of a sling. A sling, of course, does not provide adequate immobilization, and its use, without other measures, simply laid the groundwork for future recurrence. There was no diagnostic error in any of these cases, but as the war progressed, it was realized more and more keenly that diagnosis by history alone lacked scientific accuracy.

In an overseas theater, the simplest, and in the end the most economical, way of managing a soldier with a recurrent dislocation of the shoulder was to return him at once to the Zone of Interior. The prolonged hospitalization that he was likely to require, and the strong chances that the operation would fail, could not be equated with the likelihood of his return to any sort of military duty.

Many of the orthopedic surgeons who entered military service in World War II had had a great deal of experience in the management of injuries of the shoulder. A great many others had had only limited experience, and their views were derived chiefly from medical texts and journals. Much of the material on the subject, moreover, was in dispute. Maj. (later Lt. Col.) Everett I. Bugg, MC (*9*), reporting on recurrent dislocations of the shoulder from Finney General Hospital, Thomasville, Ga., began with the observation that of all the controversial subjects in orthopedic surgery, the correct surgical method of treating these injuries was supreme: Of seven chiefs of orthopedic services in general and regional hospitals in the Fourth Service Command, two were using the Nicola operation, three the Bankart operation, and one both, while one surgeon favored neither.

Opinion was just as strikingly divided in respect to the relation of proper immobilization of the primary dislocation to recurrences. Four of the seven chiefs of services just mentioned believed that correct primary immobilization would prevent, or at least greatly reduce, the number of recurrent dislocations. The other three believed that there was no relation whatsoever between primary therapy and recurrences. This was not the general opinion. Most orthopedic surgeons believed, some of them quite vigorously, that this relation did exist and that poor end results could frequently be explained by (1) too brief periods of immobilization after the

primary injury and (2) unwise management during these periods, chiefly failure to insist on early, active motion of the hand, forearm, and elbow. These errors, many surgeons believed, were responsible for more serious and more prolonged disability than the original injury.

In his analysis of the 1943 Army Air Forces conferences (*1*), Colonel Shands summed up the whole matter with the remark that the frequency of recurrences, and the number and variety of the operations devised to correct them, was a clear indication that "something is wrong with what is considered orthodox treatment of original dislocations."

No matter what their opinion might be about the effects of early therapy, orthopedic surgeons, with very few exceptions, believed that a soldier who had had an operation for recurrent dislocation of the shoulder should never again be assigned to full military (that is, combat) duty.

Variations in results and in frequency of recurrences in the hands of even well-qualified surgeons made it apparent that some operations for dislocations of the shoulder were less mechanically efficient than others. There were also other explanations for these variations. Candidates for surgery were not always selected as wisely as they should have been (p. 507), and there should also have been a more careful selection of the surgeons permitted to perform these operations. The faulty techniques of inexperienced surgeons were a principal cause of the high rate of recurrence in the Army. A surgeon capable of performing only one operation, who was obliged to limit his procedure to exploration when that technique could not be utilized, should never have been cleared for surgery for dislocations of the shoulder.

One other general point should be mentioned, that a dislocation of the shoulder was sometimes seen in association with other injuries that took precedence over it.

Surgical Management

Indications.—The patient's own story of his disability, as just mentioned, had originally been accepted at its face value. By the close of the war, most orthopedic medical officers were in agreement that if one dislocation, at least, had not been observed by a physician, surgery would not be recommended, on the ground that a patient was incapable of making the diagnosis himself. A loose body in the joint, for instance, could cause a slipping sensation that a lay person might well regard as a dislocation. Some orthopedic surgeons in the Army Air Forces required that at least one episode must have occurred in service and must have been observed by a medical officer before surgery would be recommended.

In the 175 cases in the Luck series (*2*), 15 patients had a history of two recurrences; 51 of two to five recurrences; 28 of five to 10 recurrences; and 81 of 10 to 100 or more. Symptoms had lasted from 6 months to a year

in 29 cases; to 2 years in 42 cases; and more than 2 years in 98 cases. These data were not available in the remaining cases.

In a few cases in the Luck series in which there had been only two recurrences and the second had been caused by severe, acute trauma, the question arose whether the second was a true recurrence or represented an independent dislocation precipitated by trauma after complete healing of the first dislocation. In most recurrent episodes in the Luck series, however, there was no history of fresh trauma, and the condition was regarded as a permanent defect whose correction was justified.

In a patient who experienced his dislocation in line of duty, it was the practice after the second dislocation to operate any time that he might wish. Some surgeons, though they were in the decided minority, believed that it might even be wise to operate after the first episode, since most soldiers were the "young, vigorous individuals" for whom Nicola recommended this practice.

Psychologic considerations.—Early in the war, in the selection of patients for surgery for dislocations of the shoulder, very little attention was paid to their psychologic state and their emotional maturity or immaturity. The omission was an error. The Luck series included a number of patients with psychoneuroses before induction, some of whom developed severe neurotic symptoms after operation and had to be separated from service. A number of orthopedic failures could also be attributed to anxiety states, conversion hysteria, and, most often, psychogenic elaboration. These men complained of pain in their scars and in the shoulder joint far beyond what would be expected or could be explained on physical grounds. Atrophy of the muscles was common in this group of patients, since they either had omitted the specified shoulder exercises or had carried them out in a half-hearted manner. Once the existence of the psychologic factor was appreciated, orthopedic surgeons proved entirely capable of evaluating it.

When it became evident that, even when surgery was successful, the soldier who had sustained a dislocation of the shoulder could not return to duty for 6 to 8 months, and often then could not tolerate full duty, the number of operations authorized for recurrent dislocations declined sharply. When advanced osteoarthritic changes were present in the joint and the patient had a longstanding history of many dislocations, operation was not recommended. Instead, the soldier was given a suitable change of assignment or was separated from service on a Certificate of Disability for Discharge.

Technical Considerations

At the beginning of the United States participation in World War II, the Nicola operation, which had been introduced in 1929, was the almost universal choice of surgical procedure for recurrent dislocations of the

shoulder (*10, 11*). In well-qualified hands, it was known to fail in civilian practice in 5 to 20 percent of all cases. The 20-percent failure rate was to prove almost the minimum rate in soldiers reassigned to strenuous duty, especially commando training, after operation. By the end of the war, the Nicola operation had been almost entirely abandoned.

The following techniques were employed in the 175 surgically treated dislocations of the shoulder in the Luck series:

1. The Nicola operation (transplantation of the long head of the biceps into a tunnel created in the head of the humerus) was used 94 times. In one case in the series in which the Nicola operation, done in civilian life, had been a failure, the biceps tendon was found, at the second operation, to be ruptured at its entrance into the humeral head. The surgeon redrilled the hole and passed a strip of the joint capsule through the channel to serve as the tethering agent.
2. The Bankart operation (repair and reattachment of the torn anterior capsule) was used 35 times. Introduced in 1923 (*12*), this operation came to be accepted as logical procedure, based on the repair, under direct vision, of the essential lesion.
3. The Magnuson operation (transportation of the subscapularis tendon to the greater tuberosity of the humerus) (*13, 14*) was used 26 times. With this technique, it is usually possible to identify clearly the pathologic change in the glenoid. In several operations, the Bankart and Magnuson techniques were combined by transplanting the subscapularis tendon across the intertubercular groove during closure of the wound.
4. The Roberts modification of the Nicola operation (creation of a tunnel in the head of the humerus) was used 16 times.
5. In two of the four remaining cases, the Henderson technique (creation of a fascial or tendon sling from the head of the acromion process) was used twice and the Kellogg Speed operation (a bone graft to the rim of the anterior glenoid) (*15*) was used once, when the Bankart operation that had been planned proved technically impossible. Surgery in the fourth case was limited to exploration. The enlarged head of the biceps was observed, but the long head could not be demonstrated, and the Nicola technique, the only operation with which the surgeon was familiar, could not be performed. A more experienced surgeon could in these circumstances have resorted to a Bankart or a Magnuson operation.

Visualization of pathologic changes at operation depended upon what technique was used. They were not evident at Nicola operations, nor, as a rule, at Magnuson operations, though in seven of the 26 operations in the Luck series performed by the latter technique, separation of the glenoid process was apparent. In the 35 Bankart operations in this series, the tears, most of which were confined to the anterior two-thirds of the glenoid, varied from one-half of an inch in length to the complete length of the anterior margin of the glenoid. In longstanding cases, in which there had been numerous recurrences, there was usually eburnation of the glenoid anteriorly, with degenerative changes in the glenoid articular cartilage in the form of yellowish discoloration, fibrillation, and areas of erosion.

When the operation was a secondary procedure, it was usual to find a disruption of the tendinous attachment to the articular surface of the humerus, which is a site of considerable shearing stress. The findings at Vaughan General Hospital in a recurrent dislocation, observed 10 years

after a Nicola operation, suggested that the process of attrition might predestine those who had had this operation to a delayed recurrence a number of years after apparently successful correction of the dislocation.

Errors and Technical Problems

In the Luck series, no technical difficulties were experienced in the performance of the Henderson, Speed, Magnuson, and Roberts-Nicola operations. Technical problems were encountered in the performance of the Nicola and Bankart operations. One reason was that most orthopedic surgeons did not seem to be aware of Nicola's modification (*11*) of his original technique (*10*), by which a strip of joint capsule one-half of an inch wide was drawn through the tunnel in the head of the humerus along with the biceps tendon, so that the capsular substance provided a strong reinforcement for the tendon.

The following errors and technical difficulties were listed in the reports of the Nicola operations in the Luck series (*2*):

1. The proximal end of the incision was placed too far below the clavicle instead of being ended at the inferior clavicular border. As a result, there was great difficulty, even with strenuous retraction, in visualizing enough of the shoulder joint to thread the biceps through the head of the humerus.
2. The tunnel in the head of the humerus was not made large enough. Many surgeons had the idea that, if the tendon did not fit tightly in the channel, it would not adhere to the humerus and the operation would fail. This was a misconception, as Kernwein showed both experimentally and clinically (*16*). A hole one-fourth of an inch in diameter was adequate for most tendons. It was important that the tendon be entirely free of paratendon tissue before it was drawn through the head of the humerus.
3. As a rule, a deltoid-splitting approach, one-half to three-fourths of an inch lateral to the deltopectoral junction, offered better exposure than a deltopectoral approach.
4. The ligament was sometimes sectioned to the side of, instead of in the center between, the large veins on each side of the intertubercular ligament. Hemorrhage that ensued as a result of this error might be very difficult to control.
5. In closing the capsule, it was necessary to make every effort to close the overlying bursae, to permit better mobility of the head of the humerus against the deltoid muscle. This attempt was not always made.
6. If, for any reason, it was not possible to draw the tendon through the drill hole in the head of the humerus, it was an error to make a gutter down to the hole. This error was made in two cases in the Luck series, and the dense adhesions that developed seriously limited the motion of the shoulder.

The Bankart operation (*4, 12*) was an inherently more difficult operation than the Nicola procedure (*10, 11*) and took longer to perform. Among the errors made and the technical problems encountered in its use in the Luck series were the following (*2*):

1. Separation of the subscapularis tendon from the joint capsule. The closer to its insertion the subscapularis tendon was sectioned, the greater was the chance of simultaneously opening up the joint capsule of the shoulder. This accident, which

Bost and Inman (*5*) reported in seven of 10 cases, occurred in about the same proportion in the 35 Bankart operations in the Luck series. In several reports, fusion of the subscapularis tendon to the capsule was described as if it was pathologic, which it is not. Separation of the muscular portion of the subscapularis from the underlying joint capsule was often described as difficult and as requiring careful sharp dissection.

2. Anchoring of the capsule to the glenoid margin. This was the most difficult step of the procedure, and a number of techniques were recommended for it. Some surgeons found a contra-angle dental drill useful. Others recommended pins, staples, wires, and screws. Lt. Col. Claude N. Lambert, MC, recommended suturing the capsule to the soft tissues over the neck of the scapula.

3. Reattachment of the tip of the coracoid process, a step which sometimes gave rise to considerable trouble. Occasionally a screw was used, but most often, the attachment was accomplished with nonabsorbable sutures.

Technical Modifications

Two variations in technique might be mentioned for the historical record:

1. At Finney General Hospital, before the wound was closed in any Nicola operation, the capsule and the musculotendinous cuff were dissected away from the head of the humerus to about three-eighths of an inch to each side of the bicipital groove, the base of which was roughened with a curette. The capsule was then plicated over the groove. The objective of this modification was to strengthen the capsule and to make the soft tissue fit more securely over the humerus at the point which had been weakened by opening the capsule to permit transplantation of the long head of the biceps. The technique was introduced by Major Bugg in 1941 and used by him throughout the war (*9*). He thought that the slight change in the insertion of the subscapularis resulted in a change in muscle balance simulating that described by Magnuson.

2. In the first Bankart operation performed at Finney General Hospital, considerable difficulty was experienced in placing a hole through the anterior lip of the glenoid, so that the capsule could be fitted snugly over this area. The capsule was eventually plicated tightly to the periosteum of the neck of the glenoid. As the result of this experience, two new instruments were devised, which greatly facilitated the placing of the drill holes in the Bankart procedure.

Postoperative Management

While there was considerable disagreement as to the length of time the arm should be immobilized after operation, the range being from 3 to 12 weeks, the best plan seemed to be immobilization for 4 to 6 weeks, followed by protection of the shoulder by a brace to prevent abduction for another 4 to 6 weeks.

There was no doubt that the best results in dislocations of the shoulder were obtained when early motion was practiced. An unduly prolonged convalescence was unavoidable otherwise. Some hypersensitive patients allowed their muscles to atrophy and their shoulders to become stiff be-

cause they would not tolerate the moderate amount of pain inevitable in restoring motion after surgery. In some instances, psychologic factors explained the resistance to exercise.

Some surgeons, following Nicola's recommendation, began abduction exercises on the seventh postoperative day, but did not permit the elbow to be extended beyond 90 degrees for about 4 weeks. After the Bankart and Magnuson operations, the elbow was often given free play at once, but the shoulder was routinely protected against external rotation for about 4 weeks.

Results of Surgery

Army Air Forces series.—Army medicine does not lend itself to sustained followup observations, and it can never be assumed that results reported as good shortly after treatment have sustained that evaluation. Also, while the results of the Nicola operation were generally poor, two facts concerning it must be borne in mind in evaluation of the results to be cited:

1. Hundreds of Nicola operations were performed for each Bankart operation, one reason being that many orthopedic and general surgeons were unfamiliar with any other technique.

The popularity of the Nicola operation early in the war is evident in the reports made on it at the Army Air Forces conferences in 1943 (*1*). Forty were reported from a single hospital over a 16-month period. The results, even then, were not encouraging. Nicola's own proportion of recurrences was only 4.6 percent (*11*), but in one general hospital which reported at these meetings, 18 patients were complaining of painful scars after operation and nine of the 18 had already experienced recurrences. In another hospital, in which five operations had been performed, two recurrent dislocations were observed after surgery done elsewhere; and in still another hospital, three recurrences had been observed.

2. The Bankart operation came into general use only during the last 2 years of the war, and the period of observation for it, therefore, cannot be compared with the much longer period of observation for the Nicola operation. Preliminary observations, however, suggested that the Bankart operation was likely to prove a far more satisfactory procedure for soldiers, athletes, laborers, and similar active groups.

Precise figures on immediate results are not available for the Luck series, but it was estimated that 20 percent of the Nicola operations were failures. There were no known failures in any of the other operations.

Complications in these 175 operations were surprisingly few. They included:

1. Pulmonary embolism following thrombophlebitis, which caused the only fatality in the series.
2. Pneumonia in two cases, neither severe.
3. Rheumatic fever.

4. Brachial neuritis in two cases, in neither of which the final outcome was known.

5. A single severe wound infection and several slight infections, usually around the sutures.

Failures in the Nicola procedure were open to several explanations:

1. The biceps tendon became severed at its entrance into the head of the humerus. Shearing and tension stresses on the transplanted tendon can become enormous at this point, and the fibrous connective tissue which replaces tendon tissue when tendon passes through bone is not nearly so strong as original tendon tissue.

Maj. (later Lt. Col.) John E. McDonald, MC, reporting from the Army Air Forces Regional Hospital, San Antonio, Tex., became "disenchanted" with the Nicola operation rather early in the war and attributed failures with it to tearing of the tendon around the tunnel. He, therefore, began to use Roberts' modification of the Nicola technique, in which the tendon is not cut. Again, there are no long-term results, but his patients went back to full duty in a maximum of 3 months, with some limitation in the extremes of elevation and rotation but also with stable shoulders.

2. The biceps tendon slid back and forth in the tunnel created in the head of the humerus, probably because of failure to remove paratendon and to anchor the tendon to the periosteum at its lateral exit from the new channel.

3. The drill hole in the head of the humerus was made too shallow and lay directly beneath the intertubercular groove. In his 1934 publication, Nicola (*11*) emphasized the importance of making the hole at a 45-degree-angle and having the articular surface orifice one-half to one-fourth of an inch from the lateral border of the articular cartilage.

4. In some instances, a loop of biceps tendon was seen in the joint. It was thus clear that the transplanted tendon furnished no tethering action whatsoever for the head of the humerus.

5. Profound anterior instability resulted from complete severance of the anterior aspect of the glenoidal labrum and rupture of the glenohumeral ligaments. Otherwise perfect Nicola operations ended in failure when all anterior protection was lost. In these cases, there were also, no doubt, large posterosuperior defects in the head of the humerus, although they were seldom demonstrated by roentgenograms.

6. Care was not always taken to protect the branch of the circumflex nerve that supplies the anterior portion of the deltoid.

Two other errors that contributed to poor results in the Nicola operation were reported from Harmon General Hospital, Longview, Tex., by Maj. Hira E. Branch, MC:

1. Failure to imbricate the joint capsule.

2. Failure to shorten the supraspinatus and infraspinatus tendons. With each successive dislocation, there was some lengthening of these tendons because of the scar tissue that had infiltrated them. When this

happened, the lower head of the biceps tendon was unable to hold the head of the humerus in position without the support of the surrounding structures.

Other surveys.—At Finney General Hospital, 46 patients with recurrent dislocations of the shoulder were observed between 15 May 1943, when the hospital was activated, and 1 September 1945. Of these injuries, 28 involved the left shoulder, and 15 the right shoulder: three were bilateral.

Operation was not performed in 34 cases, either because the condition had existed prior to induction and had not been aggravated by service or because the patients declined surgery.

Of the 12 patients who were operated on, eight underwent the Nicola operation and were followed up from 3 to 19 months, with an average observation of 7.4 months. There were no recurrences during this period. It is important to realize, however, that no information was available as to the type of work the men were doing or how much stress was placed on their shoulders. In none of these cases was there any difficulty in obtaining full motion of the shoulders within a month after the removal of the Velpeau bandage applied at operation.

The other four patients, two of whom had had previous unsuccessful Nicola operations, were operated on by the Bankart technique. The period of observation in all of these cases was too short to warrant any conclusions, though it might be mentioned that a patient who had had previous unsuccessful surgery had no recurrence during the 10 months he was followed.

All of the 25 Nicola operations performed at the Fort Jackson, S.C., Station Hospital were immediately successful in that the patients were returned to full duty. A limited followup, however, showed recurrences in 15 instances.

Section II. Combat-Incurred Injuries

GENERAL CONSIDERATIONS

Injuries of the shoulder with involvement of the upper portion of the humerus were frequent in World War II because the area offered a good target to snipers. Severely comminuted fractures of the distal clavicle, the glenoid, the acromial process, and the tuberosities and the head and neck of the humerus were common. Landmines and mortar shell fragments were more likely to injure the lower than the upper extremity, but shell fragments could travel considerable distances, and wounds caused by them often involved the shoulder girdle and the humerus. Self-inflicted wounds of the upper extremity were almost exclusively limited to the hands.

Associated dislocations of the head of the humerus from the glenoid were infrequent. Incomplete fractures of the head of the humerus and

similar fractures of the tuberosities, often with disruption of the rotator cuff mechanism, were the result of tangential bullet wounds.

MANAGEMENT

In the management of combat-incurred injuries of the shoulder and the head and neck of the humerus, it had to be remembered that, of all joints in the body, the shoulder has the greatest range of motion. Even when there was a major loss of its bony structures and soft tissues, if the elbow, forearm, and hand had good function, any amount of effort was justified to achieve function in the shoulder. It was essential, however, to secure healing of wounds in this region as promptly as possible, even if it meant the sacrifice of structures that might have been saved with less radical surgery. Fragments of the head and tuberosities of the humerus were excised if their vitality was at all doubtful. Flap closure of the wound, or closure with split thickness skin grafts, was undertaken as promptly as possible. The chief objective was complete coverage of the entire defect. If this was not accomplished, gross infection was the rule, and drainage was likely to be persistent. Early healing prevented excessive scar tissue formation, and when it was accomplished, a serviceable joint could often be reconstructed in spite of the loss of bony structures.

Infection was particularly likely to occur when fracture lines led into the head of the humerus. In several patients observed at Barnes General Hospital, Vancouver, Wash., avascular necrosis developed in both large and small fragments of the head of the humerus secondary to interruption by the fracture line of the blood supply of its intracapsular portion. In some of these cases, rapid absorption and replacement of the bone occurred.

In numerous minor wounds, roentgenologic examination revealed an apparently sound residual glenohumeral joint. Clinically, however, the patient might have only slight abduction function and no rotation function at all because of replacement by scar tissue of part of the capsule, particularly the rotator mechanism. In some cases, bony fragments projecting from the head of the humerus into the soft parts accounted for fixation in rotation. Many such situations could be greatly improved by excision of these fragments and of the scar tissue about the head of the humerus. The necessary excision, however, sometimes left very considerable defects in the capsule surrounding the head of the humerus, defects which it was not possible to close. These patients apparently developed new capsules of scar tissue, but even in these cases, with proper exercises and physical therapy, a great deal of improvement in shoulder motion could be accomplished in the postoperative period.

FIGURE 127.—Gunshot fracture of greater tuberosity of humerus. Anteroposterior roentgenogram of shoulder with arm abducted showing fracture of greater tuberosity with fragmentation due to bullet wound. As is usual in such cases, there was disruption of the rotator mechanism with marked loss of rotation at the shoulder. Considerable improvement in function followed surgical repair of the capsule and rotator cuff. (Adams, C. O., and Luckey, C. A.: Fractures of the Humerus. [Unpublished data.])

Technical Considerations

Bony spurs and dense scar tissue could sometimes be removed from the posterior aspect of the head of the humerus by a longitudinal approach in the posterior shoulder region. If the deltoid fibers were split down in this region approximately 2½ inches from the acromial process and if the posterior axillary nerve was isolated and protected, good visualization could be secured. When fixation was the result of scarring or of bony spurs on the medial aspect of the joint, excellent visualization could be obtained through an axillary approach, and very good results were achieved by appropriate plastic procedures. The axillary approach, however, did not provide adequate exposure for any extensive reconstructive surgery of the scapulohumeral joint.

When the skin incision was made anteroposteriorly along the normal flexion crease in the axilla, the short head of the biceps could be retracted medially, along with the coracobrachialis, and enough exposure could thus be obtained to excise any scar tissue present. At the same time, the major nerve trunks and vessels could be kept completely out of the surgical field. Retraction of the short head of the biceps and of the coracobrachialis laterally and superiorly would have provided a somewhat more extensive

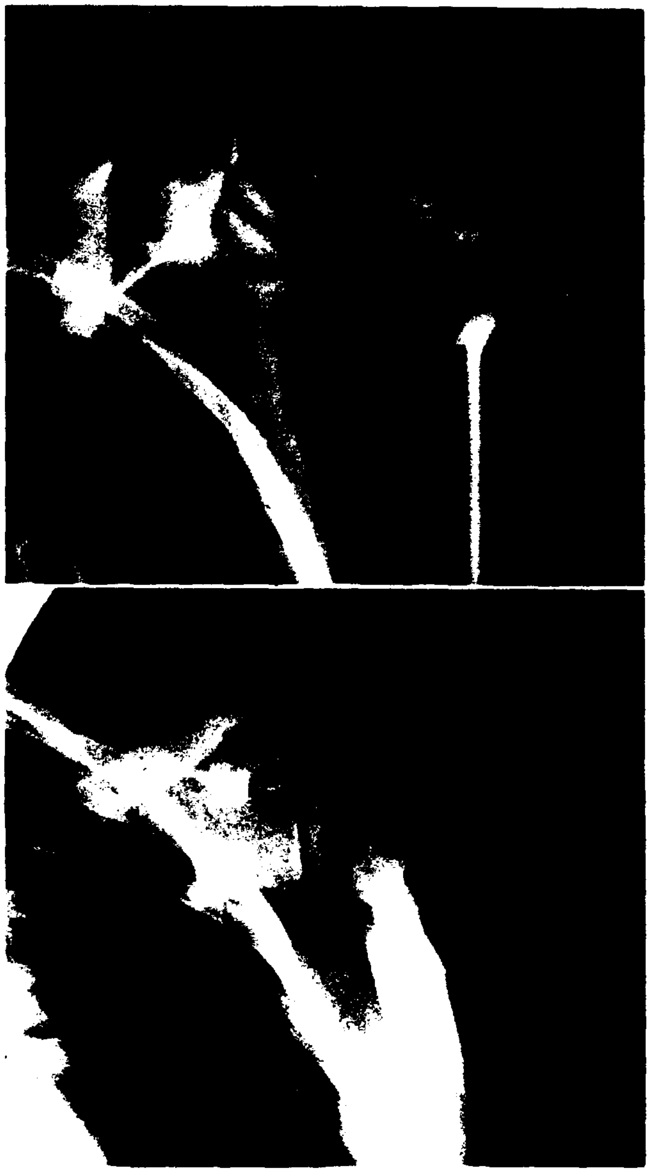

FIGURE 128.—Fracture of upper shaft of humerus or surgical neck. (Top) Anteroposterior roentgenogram of shoulder with arm widely abducted showing malposition of fragments. If this fracture had been reduced originally, it had displaced in the plaster spica during transportation. There is frank nonunion. (Bottom) Anteroposterior roentgenogram of same fracture 5 months after reduction. There is obvious loss of substance of some of the humeral head, but the articular surface is intact and the fracture is firmly united. (Adams, C. O., and Luckey, C. A.: Fractures of the Humerus. [Unpublished data.])

exposure of the joint, but the major nerves and vessels would then lie exposed in the posterior portion of the wound. If this technique was used, the greatest care had to be taken to protect them.

FIGURE 129.—Gunshot wound of shoulder region. Posteroanterior roentgenogram of shoulder joint 1 year after gunshot fracture of head and neck of humerus sustained in combat. The roentgenogram reveals marked disruption of the shoulder joint and healed fractures, with downward luxation of the humeral head. The functional result was excellent, the patient having no pain with active abduction to 90 degrees.

Results of Surgery

Even when there had been considerable disruption of the head of the humerus and other structures of the shoulder joint, as well as considerable soft tissue damage, there was remarkably satisfactory function and very little discomfort in many correctly treated injuries (figs. 127–130). On the other hand, when immobilization had been unduly prolonged, with the arm adducted and internally rotated across the chest wall, there was usually considerable residual disability. With early motion, loss of glenoid-humeral motion was largely compensated for by scapulothoracic motion. A range of 80–90 degrees of motion in the shoulder meets the needs of most persons in civilian life.

Arthrodesis

Arthrodesis had a definite but extremely limited field of usefulness in combat-incurred injuries of the shoulder. In some shoulder joints irreparably damaged by combat wounds or other trauma, if the hand and forearm were intact and the nerve and vascular supply unimpaired, surgical arthrodesis of the humerus to the scapula gave the patient a very useful upper extremity (fig. 131).

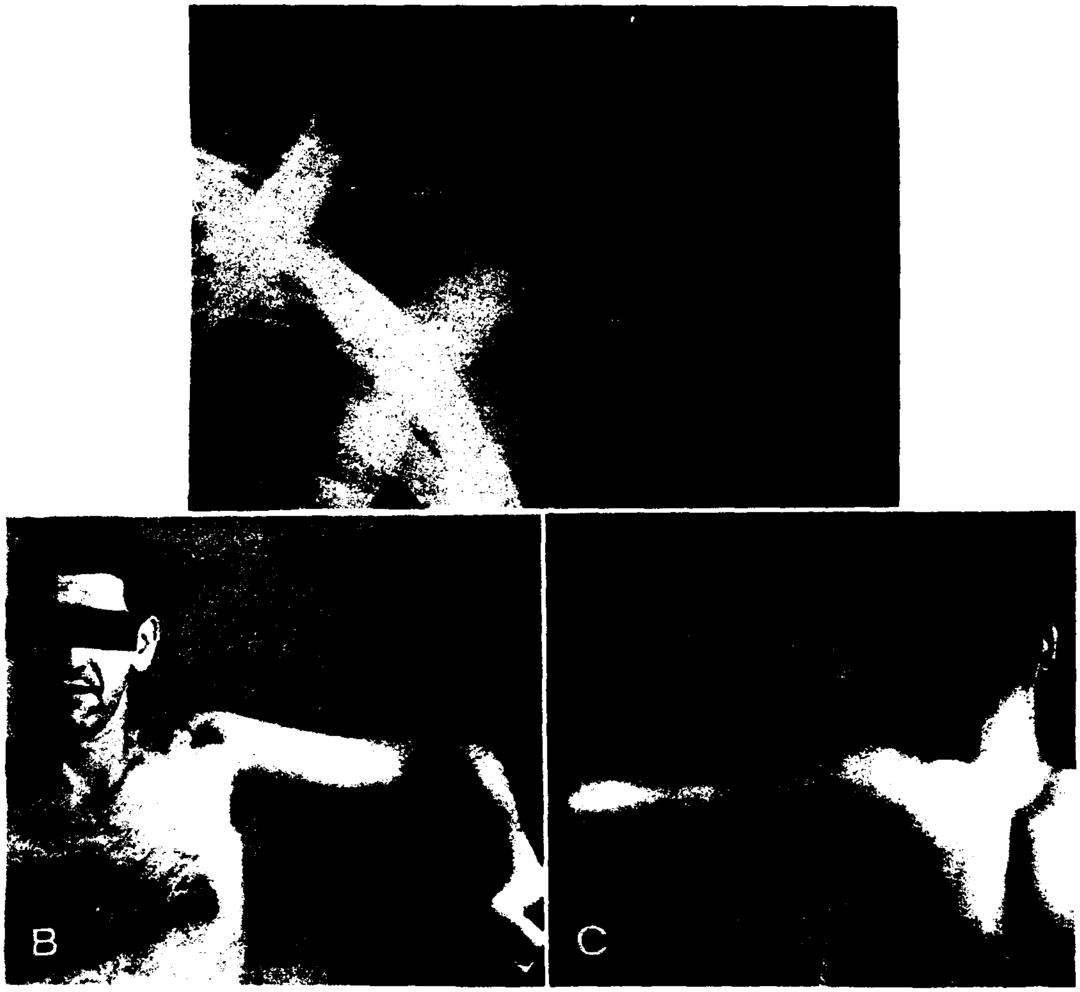

FIGURE 130.—Gunshot wound of shoulder region. A. Posteroanterior roentgenogram of left shoulder showing spontaneous ankylosis of shoulder joint 1 year after compound fracture of humerus and adjacent scapula from gunshot wound. Osteomyelitis followed. Fixation in the functional position was secured by plaster-of-paris spica. The wounds had been healed for 2 months, after adequate sequestrectomy. B and C. Anterior and posterior photographic views showing healed wound and active abduction to 90 degrees without pain or discomfort through scapulothoracic motion. This was another excellent functional result.

The limitation of motion that was sometimes a considerable handicap after arthrodesis was improved in three cases by Maj. Joseph E. Milgram, MC, at Schick General Hospital, Clinton, Iowa, by an operation based on the following reasoning: When a shoulder joint has been arthrodesed by trauma, infection, or surgery, subsequent ranges of motion of the resultant scapulohumeral complex are obtained at adjacent joints. The motion of the scapula, however, is limited by the configuration of the thorax and by the range of motion of the clavicle at its inner end and at the acromioclavicular

FIGURE 131.—Use of arthrodesis for otherwise insoluble problem in serious combat injury of right shoulder joint. (Top) Anteroposterior roentgenogram showing badly shattered and disrupted shoulder joint with fragmentation of upper portion of humerus. Note numerous foreign bodies in soft tissues. (Bottom) Same, after tibial graft had been driven across glenoid into scapula and fixed to medial surface of humerus by three screws. The arthrodesis was obviously solid when this roentgenogram was made.

joint. If that portion of the clavicle which extends from the point of attachment of its trapezoid and conoid ligaments to the acromioclavicular joint were excised, a substantial increase in motion could be anticipated in certain planes. In each of the three cases in which this reasoning was applied clinically, the range of adduction with the arm elevated, and of internal rotation with the arm at the side, was substantially increased, without postoperative pain or loss of strength. The improved range of abduction expected on theoretical grounds, however, did not occur.

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CHAPTER XVII

Injuries of the Shaft and Lower Portion of the Humerus

Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

Section I. Noncombat Injuries

MID SHAFT

Noncombat fractures of the mid shaft of the humerus were usually of the simple spiral type. Treatment sometimes called for skeletal traction, which could be accomplished as balanced suspension traction in bed or incorporated in a shoulder spica if the patient could be ambulatory. Most patients with these injuries needed a shoulder spica at some stage of treatment and transportation. A hanging cast was sometimes used, but it did not furnish a satisfactory means of immobilization for transportation; when it was used at other times, careful supervision was necessary, to make sure that the patient did not temporarily lose the function of the shoulder joint and end with some permanent stiffness.

LOWER THIRD

Fractures of the lower third of the humerus tended to heal in the varus position, though the importance of preventing this deformity by immobilizing the forearm in pronation was emphasized repeatedly in the instruction of new inducted medical officers, just as it was in the literature. This was a most unfortunate occurrence, for severe angulation placed the musculature of the elbow joint at a great mechanical disadvantage. In one series of 24 unselected fractures of the lower third of the humerus observed at Ashford General Hospital, White Sulphur Springs, W. Va., varus deformity at the fracture site occurred in 16, with the degree of disability proportionate to the degree of deformity (*1*). One injury of this kind had to be corrected by osteotomy and immobilization of the hand and forearm in pronation.

Medial angulation of the distal fragment was another common deformity in fractures of the lower portion of the humerus. It could often be corrected by keeping the forearm in pronation, by the technique devised at Ashford General Hospital (*1*).

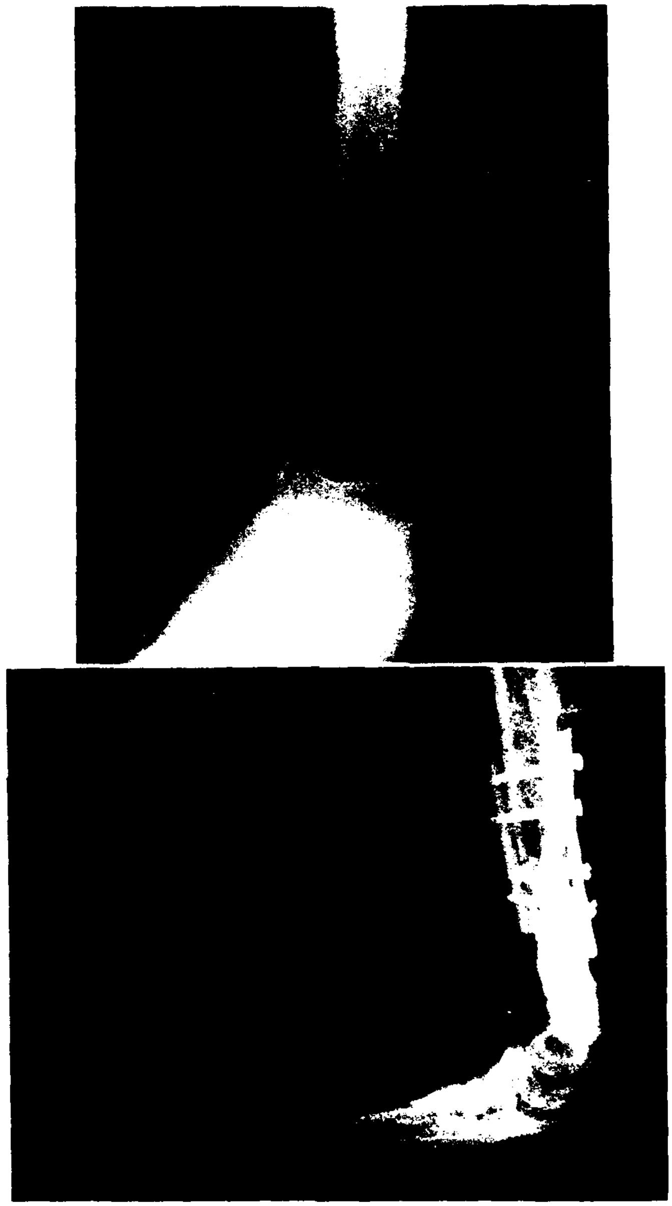

FIGURE 132.—Bone grafting in severely comminuted fracture of lower third of right humerus. (Top) Lateral roentgenogram showing fracture with involvement of the radial nerve. The meager data available do not state whether the nerve was divided nor do they state the origin of the *fracture.* (*Bottom*) *Postoperative* lateral *roentgenogram* of same humerus after removal of comminuted fragments, shortening of humerus, and fixation of major fragments. The two rigid bone grafts are firmly fixed to the proximal and distal fragments of the humerus and to each other by four stainless steel screws. The approximation of fragments and bone grafts is excellent. No further information is available on the status of the radial nerve.

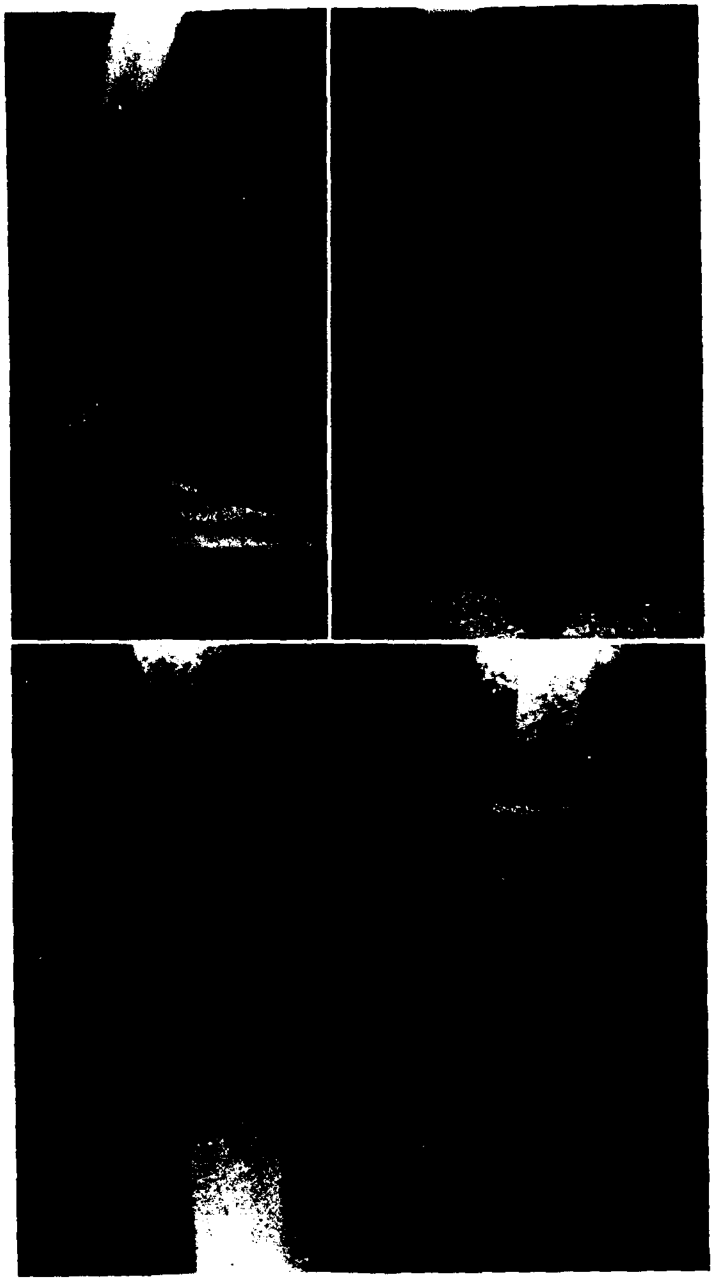

FIGURE 133.—Compound comminuted fracture of shaft of humerus at lower third. (Top) Anteroposterior and lateral roentgenograms showing un-united compound comminuted fracture. At operation, the fracture site was dissected out to allow accurate reduction. Fixation was accomplished by the use of a tibial bone graft with four screws which transfixed the graft and both humeral cortices. (Bottom) Anteroposterior and lateral roentgenograms of same humerus 6 months after operation, with fracture now solidly united and bone graft and screws in situ. (Adams, C. O., and Luckey, C. A.: Fractures of the Humerus. [Unpublished data.])

Inadequate union and nonunion of fractures in the lower portion of the humerus were treated by bone grafts (figs. 132 and 133), sometimes with bone from the ilium, more often with cortical bone from the upper tibia. The graft usually was placed on the posterior aspect of the bone, but sometimes it was necessary to place it at an angle and build up a bridge from the posterior aspect of the lateral condyle to the shaft above, to avoid placing the graft where it would interfere with the tip of the olecranon as it glided into the olecranon fossa. When the nonunion was low, a Y-shaped graft was occasionally used. Rather firm fixation was necessary to control the position of the lower fragment.

TRAINING INJURIES

Most of the fractures of the humerus sustained in training at Camp Swift, Tex., and other training camps were treated in a hanging cast. The functional results were usually good, but the anatomic results were only fair.

The same policy was used at Camp Maxey, Tex., where two disadvantages were reported:

1. A tendency to outward bowing was very common unless the casts were carefully applied.
2. A great tendency toward shrinkage often allowed the cast to settle to such a degree that its upper edge was brought close to the fracture line and it thus acted as a lever to produce angulation.

In a training injury observed at this camp, a long spiral fracture, with good alinement, occurred spontaneously after the trainee had thrown a hand grenade. In another instance, when a transverse fracture at the junction of the middle and lower thirds of the humerus finally came to open reduction, the distal fragment, which had angulated anteriorly, was found deeply embedded in the superjacent brachialis muscle. The manner in which the fragment was impaled in it almost severed the muscle, and the enormous amount of callus formation was caused partly by damage to the muscle. Fortunately, the range of elbow motion was not impaired.

Section II. Combat-Incurred Injuries

UPPER SHAFT

Combat-incurred fractures of the head of the humerus were apt to be caused by gunshot wounds and to be associated with fragmentation. Avulsion fractures of the greater tuberosity also occurred, as when the head of the humerus was dislocated from the glenoid.

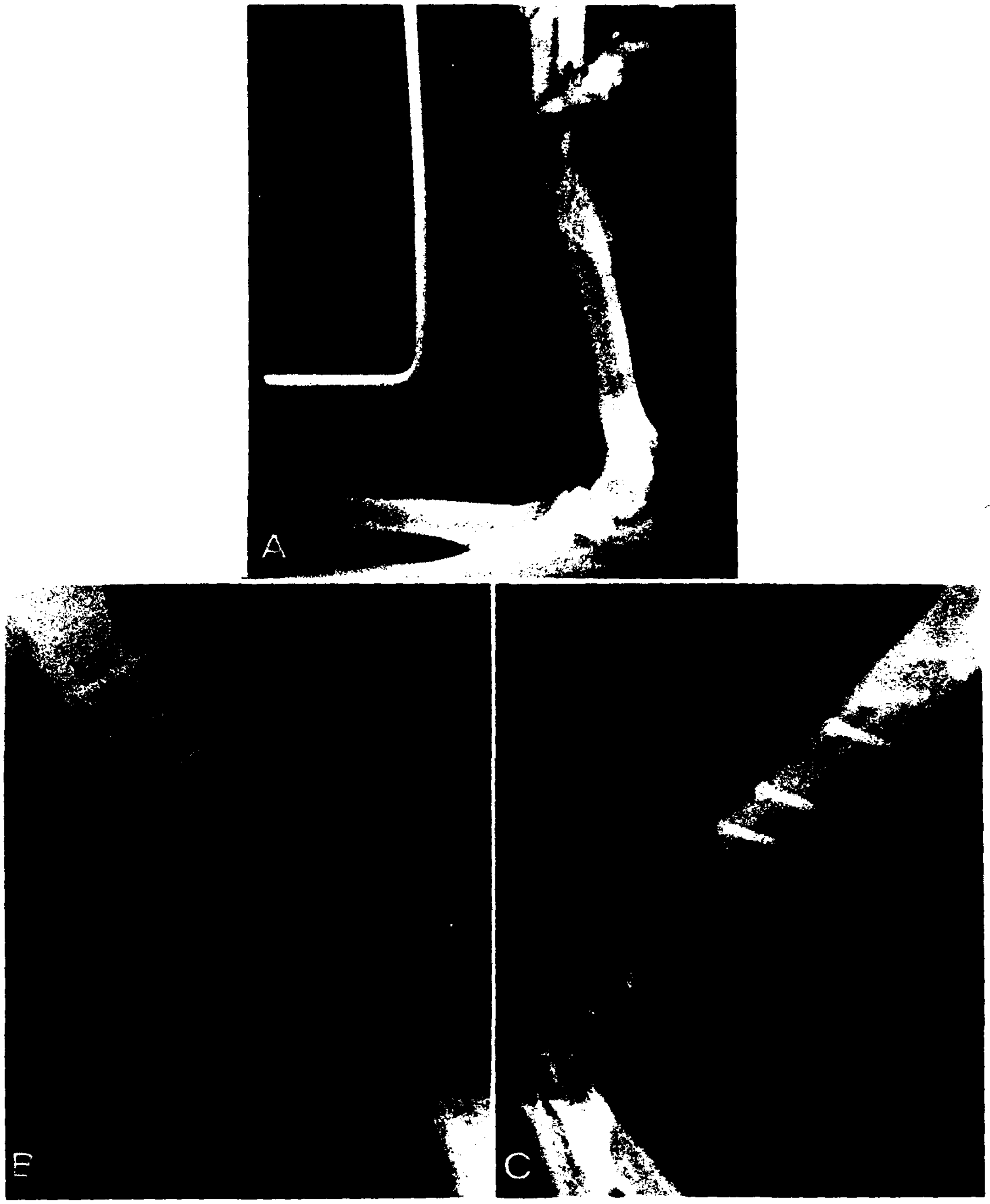

FIGURE 134.—Internal fixation in severely comminuted fracture at middle third of humerus. The presence of metallic foreign bodies suggests that a shell or gunshot wound was the cause. A. Lateral roentgenogram showing fracture. B. Postoperative anteroposterior roentgenogram of same humerus after removal of many comminuted fragments. The proximal and distal fragments of the humerus are fixed by two rigid bone grafts which are also fixed to each other by five stainless steel screws. The radial nerve was repaired at the same operation. C. Lateral postoperative roentgenogram of same humerus, showing excellent alinement and fixation of the fracture. The surgeon who operated on this patient noted that with the removal of loose fragments, good bone was brought into contact with good bone and the screws that penetrated both grafts assured viselike fixation.

FIGURE 135.—Complete compound comminuted fracture of mid shaft of left humerus, with radial nerve paralysis. A. Posterior view of left arm with draining wound 3 months after injury. B. Lateral roentgenogram showing sequestra and bone infection. C. Anteroposterior roentgenogram showing same.

MID SHAFT

Battle-incurred injuries of the mid shaft of the humerus (figs. 134 and 135) were usually caused by bullets or by shell fragments. Internal fixation was frequently required and was accomplished by transfixion screws if comminution was not too extensive; otherwise, by plating or bone grafting. Dissection of soft parts from the bone was as limited as possible. Sub-

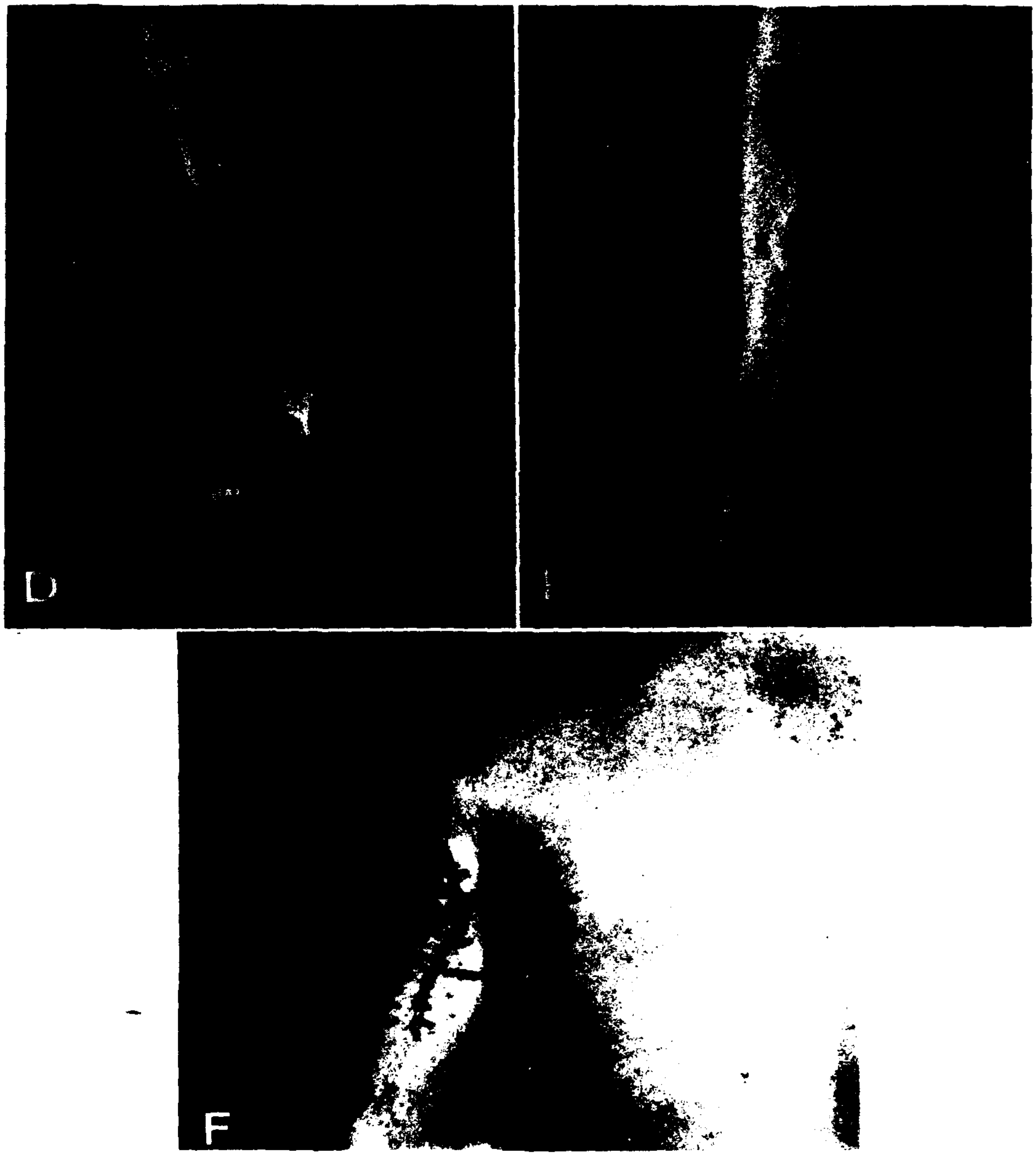

FIGURE 135.—Continued. D. Lateral roentgenogram 2½ months after first-stage operation showing fracture united with no evidence of osteomyelitis. E. Anteroposterior roentgenogram showing same. F. Posterior view of left arm showing healed wound 2½ months after closure, with no recurrence of infection.

periosteal stripping of major fragments or free fragments was contraindicated and was avoided by the use of long skin incisions and long dissections in the muscle planes.

If sequestra or foreign bodies were present, their removal was usually followed by rapid healing of the wound. Persistent sinuses were not common. Nonunion or inadequate union was easily handled by bone grafts, preferably from the ilium. Cortical grafts from the upper portion of

the tibia were also used in some cases in which there was free motion at the fracture site or in which the un-united fragments could be dissected out and a new relation of fracture fragments obtained when bone grafting was done. The procedure furnished temporary internal fixation and also stimulated osteogenesis.

In fractures of the mid shaft of the humerus, care had to be taken to maintain the function of the elbow and shoulder joint, or to reestablish it if it had been lost.

LOWER THIRD

Combat-incurred fractures of the lower portion of the humerus were often extensively comminuted, the comminution sometimes extending upward to the shoulder joint or downward into the olecranon process and the proximal portion of the radius. When the fracture lines extended into the elbow, pyogenic arthritis was sometimes a serious complication. Any prolonged infection about the elbow joint resulted in scarring and loss of function. On the other hand, if scarring could be prevented, a remarkable degree of elbow function was often possible, even when rather large fragments of the lower portion of the humerus were lost. It was, therefore, the practice to remove any fragments likely to become necrotic because of interference with their blood supply or likely to sequestrate.

SPECIAL PROBLEMS

Extensive scarring of the triceps musculature often extended down to the humerus and prevented movement; flexion was prevented by bowstring action and extension by fixation of the triceps itself (*2*). The scar tissue could be dissected out and the triceps separated from the bone by the interposition of some gliding material such as fascia, taken from the same arm or from the opposite arm or leg. Cellophane was used in a few instances at Barnes General Hospital, Vancouver, Wash., with satisfactory results.

Infection was generally easier to control in the humerus (and other parts of the upper extremity) than in weight-bearing bones, in which weight-bearing, dependency, and a less liberal circulation acted as adverse factors. In the humerus, the cortex is much thinner than it is in the weight-bearing bones, a factor which allows more rapid demarcation and absorption of sloughs or sequestra. Finally, adequate drainage of the whole region about the humerus is also more easily obtained than in the lower extremity.

Even when chronic bone infection developed in combat-incurred wounds of the humerus, the use of antibiotics and saucerization and grafting, by the dermatome technique developed at Ashford General Hospital, usually led to prompt healing (*1*).

Involvement of the regional nerves (median, radial, and ulnar) was not frequent in combat-incurred injuries of the lower portion of the humerus.

BONE GRAFTS

A number of precautions in bone-grafting of the humerus were peculiar to this special bone (*1*):

1. When radial nerve severance and nonunion of fractures of the humerus coexisted, the orthopedic and neurosurgical procedures could be carried out together. Exposure of the nerve was usually necessary to approach the humerus, and possible nonunion had to be taken into account or the nerve would be subjected to the hazard of distraction of its sutured ends. Also fibrosis resulting from a separate operation for nerve repair would prejudice return of function. If necessary, the humerus could be shortened somewhat to obtain better nerve repair.

2. Nonunion close to the elbow was difficult to handle without jeopardizing the function of the elbow joint. To provide an adequate bed for a graft on a short distal fragment, a paddle-shaped graft could be applied to the wide supracondylar flare of the humerus. If the olecranon fossa was impinged on by the graft, the olecranon process would ultimately have to be sacrificed or some plastic procedure on the fossa carried out. If encroachment of the graft on the joint seemed likely, posterior application of the graft was preferred.

3. Severe osteoporosis that could jeopardize successful fixation of a bone graft was more frequent in the humerus than in other bones. The suggestion made by Maj. (later Lt. Col.) Carlo S. Scuderi, MC, McGuire General Hospital, Richmond, Va., was useful, that fixation screws by inserted first through the host bone and then into the healthy cortex of the graft. Washers of the same material were used. To attempt screw fixation, which was adaptable only to stronger bones, in the face of extreme osteoporosis of the humerus, was to invite failure of the graft. Success was far more likely by anticipation of the severity of the possible osteoporosis and adaptation of the fixation technique to the mechanical requirements of the special case.

4. Gaps intervening between the ends of fragments of the humerus filled in very slowly unless osteogenetic bone was used for the grafts.

5. One of the greatest difficulties in bone grafting of the humerus was the satisfactory application of plaster immobilization while the patient was under anesthesia. If the preoperative range of shoulder motion had been free, he could be returned to some form of balanced continuous traction, including a hanging cast adapted for temporary traction in bed. In nonunions high in the shaft, the upper fragment might be in a position of marked internal rotation, and to secure union in the proper position of

rotation, without torsion on the graft, the forearm had to be immobilized across the body.

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CHAPTER XVIII

Injuries About the Elbow

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

Section I. Noncombat Injuries

When the United States entered World War II, there was no general agreement on the best methods of treating injured elbows. This was evident in the discussions at the Army Air Forces conferences (*1*) in 1943 (p. 81). Dr. John Dunlap of Pasadena, Calif., for instance, reported good long-term results in cases treated by skin traction, but only a few medical officers advocated this method. If fractures of the condyles could not be brought into good alinement by this technique, then open reduction and internal fixation had to be used. Other recommendations included the use of small Kirschner wires for fixation of displaced condyles and skeletal traction with a Kirschner wire through the olecranon. Many of the speakers advised that traction be applied with the shoulder in a spica cast in 90-degree abduction. Fixation with small plates and screws was recommended for T-fractures.

INJURIES OF THE HEAD OF THE RADIUS

General Considerations

Most noncombat fractures of the head of the radius were the result of falls with the elbow fully extended and the forearm pronated. Force transmitted through the radius drove the radial head against the capitulum and the external condyle of the humerus.

The clinical picture was fairly characteristic. The elbow was held in semiflexion and pronation. Any attempt to change this position was painful. Physical findings included swelling over the elbow and radius, ecchymosis of varying degrees, and great tenderness on palpation of the radial head. Crepitus was not usual.

The disagreements as to treatment of injured elbows were again plainly evident in the discussion of injuries of the head of the radius at the 1943 AAF (Army Air Forces) conferences, particularly in regard to the

period of immobilization if conservative measures were used. It was finally concluded that, if the fracture was incomplete, or if it was incomplete and was not displaced, immobilization either should be omitted, or, if it was used, should not be continued for more than 2 weeks. When immobilization in the semiflexed position was continued for more than this period, many patients were left with considerable disability, including painful elbows, loss of flexion and extension, and impairment of supination and pronation of the forearm.

When a fracture of the head of the radius was comminuted and displaced, it was the majority opinion of the conferences that early excision of the fragments and of the rest of the head was the best plan, though a minority of the officers believed that, if the fractures involved less than a third of the articular surface, removal of only the fragments was sufficient. Anterior, posterior, and posterolateral approaches were all recommended. The surgeons who recommended the (more difficult) anterior incision believed that, with it, there was less chance of subsequent extra-articular calcification.

There was general agreement that, if excision of the fragments and of the remaining portion of the head was clearly indicated, operation should be performed promptly, preferably as soon as possible after injury. If, on the other hand, there was any doubt as to the necessity for this procedure, it should be deferred until the indications were clarified. It was agreed that excisional surgery should never be done during the period of new bone formation after the fracture.

Proof of good results with both conservative and surgical measures was forthcoming (*1*). One analysis concerned nine patients, three treated by surgery with good results and six treated conservatively with five good results. Surgery was eventually required in the sixth patient in the latter group, and he was left with slight limitation of flexion. Another analysis concerned 30 injuries, 24 of which were treated by the closed method with an average hospitalization of 31 days and six by open surgery with an average hospitalization of 52 days. In both groups, the best results were obtained when movement was begun not later than the fifth day. In this, as in all other reports, there was emphasis on active, not passive, motion.

Numerous reports at the 1943 AAF conferences, from both civilian and military sources, concerned excessive calcification about the elbow joint after excision of the radial head. The resulting limitation of motion sometimes took the form of complete ankylosis. Among recommendations for preventing extra-articular calcification, or reducing its severity, were coverage of the end of the radius with muscle and soft tissue when the operation was concluded and immobilization of the extremity for 2 weeks after excision of the head.

Other disabling complications reported following removal of the radial head were radial deviation of the wrist, with associated pain and weakness, and lateral instability of the elbow.

Typical experiences with injuries of the radial head in World War II are well illustrated in detailed reports from a station hospital and a general hospital in the Zone of Interior.

Station Hospital, Camp Joseph T. Robinson

At the station hospital at Camp Joseph T. Robinson, Ark., Maj. James A. Mason, MC, and Capt. Ned M. Shutkin, MC, treated fractures of the radial head and neck by immediate active motion, local heat, and a simple arm sling (*2*). They could find in the literature to date only two reports on the use of comparable techniques, by Neuwirth (*3*) in 1942 and by Colp (*4*) in 1930; the latter advocated immediate resection, regardless of the degree of capital displacement, followed by immediate active motion.

Rationale of therapy.—Major Mason and Captain Shutkin emphasized that the therapy they advocated was based on certain anatomic features of the elbow joint.

> This joint is unique in that it is bicondylar. The humerus articulates with the radius and ulna, and the proximal ends of the radius and ulna are in close approximation and relation. The two condylar joints, however, do not have the same axis and do not move through the same arc. If a normal range of flexion and extension is to be achieved, the action of these two joints must be perfectly synchronized. Any anatomic variation that disturbs the action or arc of either will produce some degree of mechanical block. Reduction of the fragments of a fractured elbow may eliminate all obvious deformity but still may not restore synchronization and full function.

Major Mason and Captain Shutkin also emphasized the dual function of the head of the radius:

> It articulates with the ulna to form the proximal radio-ulnar joint, through which rotation of the forearm is executed, and it maintains lateral stability of the elbow joint. The close relation between the head of the radius and the ulna is an important consideration, since exuberant callus formation may ankylose the proximal radio-ulnar joint and thus impair rotation of the forearm.

Roentgenologic evidence, in the opinion of these observers, had not proved reliable in indicating whether or not the position of the fragments was normal anatomically, and fixation until calcification had occurred would, therefore, do nothing beyond insure that synchronization was lost and bony blockage of the joint would result. At this stage, massage, active and passive motion, and other standard physical measures would do actual harm by compressing the articular cartilage, initiating a hypertrophic arthritis, or producing a hematoma that might rapidly ossify.

The premise on which standard conservative treatment of fractures of the radial head was based was the attempt to restore the articular surfaces to their normal anatomic status and then employ some technique of fixation to hold the fragments in position until sufficient callus had formed to prevent further displacement when motion was attempted. The technique used at the Camp Robinson hospital, essentially immediate motion and no

immobilization, was based on the assumption that the fragments to be dealt with were small and uncontrollable. If active motion of the elbow was begun promptly, before they became fixed, they would be moved across the fixed, uninjured articular surfaces of the humerus and thus would attain the best functional position in relation to the various joint surfaces.

Technique.—In this method, the only fixation of the elbow was by a simple sling, which held it at a right angle, in as nearly neutral a position as possible. Continuous hot wet packs were used as long as necessary to overcome muscle spasm and treat any soft-tissue injury that might be present. Twice a day, beginning immediately after injury, a medical officer guided the elbow gently through its range of active motion. Extension and flexion were performed with the forearm in supination, and an attempt was made to have the patient balance his range of flexion with an equal range of motion in extension. The forearm was also actively moved through its range of supination and pronation. The patient himself performed all motions. The medical officer simply supported and guided the arm. At no time was forceful passive motion used. If the procedure was carried out carefully, no degree of force was required. Passive force was not used except in entirely uncooperative patients, and then only after the third week, to a minimum degree, and with great caution.

One of the advantages of this technique was the improvement it produced in the local circulation, which in turn reduced the amount of soft-tissue scarring and the degree of soft-tissue contracture. Close observation of the injured part was also always possible, and any complications, such as nerve damage or Volkmann's ischemic contracture, could be recognized and treated at once.

Results.—The technique described was used in 18 of the 25 patients with fractures of the head of the radius admitted to the hospital at Camp Robinson between 18 May 1941 and 15 August 1942. The other seven were treated by conventional methods, which meant fixation for periods from 10 to 30 days.

In evaluating results, function was classified as 100 percent only when the patient had normal, painless muscular power and had no limitation of range of motion, or no more than 5 percent by actual measurement.

The only patient in the group with a comminuted fracture of the head of the radius with marked displacement was transferred to an Army general hospital, where he was operated on and hospitalized for 87 days. Final function was 60 percent. This is the type of injury for which early resection is usually advised.

The remaining 24 injuries were grouped and evaluated as follows:

1. Linear transverse fractures without displacement and transverse impacted fractures of the neck without displacement:

In the three conventionally treated cases in this group, the period of hospitalization ranged from 37 to 198 days and averaged 93 days. Return of function corresponded

with the period of hospitalization. Two of the three patients had 100-percent function and the other, 70-percent.

In the 11 patients treated by the new method, excluding an uncooperative, hysterical patient who required treatment for 49 days, the period of hospitalization varied from 9 to 51 days and averaged 36 days. Function was attained in 17 to 42 days and was 100 percent in every instance.

2. Comminuted fractures of the head without displacement or with minimal displacement, and fractures of the No. 1 category with complete dislocation of the elbow.

In the three conventionally treated cases in this group, the period of hospitalization ranged from 85 to 118 days and averaged 107 days. Function was attained in an average period of 107 days and was rated 90, 89, and 50 percent, respectively.

In the seven patients treated by the new method, the period of hospitalization varied from 49 to 58 days and averaged 53 days. Function was attained in an average period of 48 days and was 100 percent in five cases and 95 percent in the other two. Both of these patients had complete posterior dislocations of the elbow.

Of the six patients in this series who were treated conventionally, five had calcification in the soft tissues about the elbow. Of the 18 treated by the immediate-motion, no-immobilization method, only one showed any tendency to calcification and the process was not extensive, though the injury was a fracture-dislocation of the elbow with great swelling of the joint.

In the six conventionally treated injuries, followup roentgenograms showed no essential change in the position of the capital fragments after reduction. In the active-motion cases, roentgenograms in five cases showed further slight to clear-cut displacement of the small, uncontrollable fragments of the radial head, a somewhat perplexing finding, since all the patients were progressing satisfactorily and had 95- to 100-percent good end results to date. In a comminuted fracture of the radial head with longitudinal splitting, impaction of the neck, and moderate displacement of the fragments, 100-percent function returned in 6 weeks and check films showed a more normal appearance, with only two small fragments visibly displaced, as compared with four on the earlier film.

These observations seemed to corroborate the premises on which the Camp Robinson treatment was based; namely, that anatomic reposition of the displaced fragments is not necessary to regain synchronization of the joint surface but that, on the contrary, early active motion permits these fragments to assume optimum functional positions in relation to fixed uninjured articular surfaces.

It is scarcely necessary to point out that the results achieved, favorable as they are, are entirely inconclusive. The series is too small to be of statistical value, and since in no instance was the followup longer than a year, posttraumatic arthritis of later development cannot be excluded. Within

these limitations, however, this seems a valuable method for treatment of fractures of the radial head.

Oliver General Hospital

Analysis of material.—The experience with injuries of the radial head at Oliver General Hospital, Augusta, Ga., was reported by Lt. Col. Harold C. McDowell, MC (*5*), and covered 42 cases, including one patient with partial radial nerve damage caused by excision of the head of the radius elsewhere. He recovered completely under conservative treatment. The other 41 cases fell into two groups:

1. Fourteen simple fractures of the head of the radius had been treated elsewhere by excision of the head, which had been followed by proliferation of callus and such extreme deformity that reexcision was necessary. Similar deformities had followed some of the early resections performed at this hospital until the technique was modified as follows: A large portion of the proliferated capsule about the head of the radius was removed as soon as the head was removed. Hemorrhage was controlled by ligature. The period of postoperative immobilization was shortened, and early active and passive exercises were begun under supervision. Small doses of deep X-ray therapy (600 r) were begun 48 hours after operation. This supplemental therapy greatly reduced the hospital stay-days and improved the results, particularly in patients with a high threshold of pain.
2. Twenty-seven patients had severely compounded, comminuted fractures, involving the condyles, humerus, and ulna, as well as the radial head. All of these patients had partial fibrous ankylosis, and 11, all of whom required sequestrectomy, had osteomyelitis. Radial sequestrectomy was not necessary in any instance, but in a number of cases, fragments were removed which were blocking flexion, particularly when the medial condyle of the humerus had sustained the principal injury. In these cases, immobilization was discontinued after a week and the patients were instructed to flex the elbow actively while the wound was healing, in an effort to gain a few degrees of flexion and to decrease the extent of the surgery necessary later, when the wound was completely healed.

Technique.—Operation was not undertaken if the injury was no more than a chip fracture and if interference with function was insignificant. Immobilization was discontinued in these cases as soon as the patients were processed after admission, and physiotherapy and active exercises were begun immediately. Results were uniformly good and limitation of extension was only slight.

Only the blocking fragments were removed at operation. Radical resection was thought to carry too high a risk of the development of an unstable, painful, useless joint. As a rule, the operation was done in stages. In the first stage, an attempt was made to remove the fragments blocking flexion. Several weeks later, after the optimum range of motion had been obtained and the muscles of the arm had been redeveloped, a second-stage partial operation was done to remove the block to extension. It included partial capsulotomy of the anterior capsule, especially that portion lying just posterior to the biceps brachii tendon. In unusually severe cases, when

the radial head was seriously damaged, a third-stage resection was undertaken, after maximum motion had been obtained in the elbow proper.

The following technique was used in resection of the radial head:

A longitudinal incision, about 4 inches long, was curved to either the lateral or the medial side of the olecranon, depending upon which condyle of the humerus was more severely comminuted. The ulnar nerve was identified, partly freed, and retracted out of the field. A Z-shaped incision was made in the triceps tendon, to provide adequate exposure of the joint; this technique, because of the importance of early active motion, was considered preferable to turning up a portion of the olecranon with the attachment of the triceps tendon intact. A type of Z-incision of the tendon also allowed for lengthening of the triceps tendon, which was often necessary.

Fibrous fusion was destroyed by blunt and sharp dissection, and comminuted fragments were removed until a good range of passive motion was achieved. If cartilage was still present, care was taken to leave it intact on one joint surface, to permit early pseudoarthrosis. A sufficient amount of bone was always removed from the surface not containing cartilage to allow for an adequate joint space, though not to such an extent that instability resulted.

When it was necessary to repair the triceps tendon, fascia lata was laced through its remnants and anchored firmly to the remnants of the olecranon through drilled holes.

Results.—When this report was made, 21 of the 27 patients at Oliver General Hospital with compound comminuted fractures involving the head of the radius had undergone either first- or second-stage partial resection. Although the followup was, of course, entirely inadequate, it seemed that a moderate range of motion would be attained in every instance and that arthrodesis would not be needed in any.

The active range of motion obtained depended in large measure upon the cooperation of the patient and the level of his threshold for pain. For this reason, patients were retained on the wards for long periods of time, so that they could be closely supervised. In spite of this precaution, two patients with a low threshold for pain allowed secondary fibrous fusion to develop and had to undergo secondary resection.

Complete arthroplasty was not undertaken in any of these 27 cases for several reasons: The fractures were recently compounded. All were severely comminuted. Complete bony ankylosis of the elbow offers the best prospect for good results following arthroplasty, and fibrous rather than bony ankylosis was present in these cases. Remnants of cartilage present on a portion of the remaining joint surface enhanced the possibility of obtaining pseudoarthrosis after partial resection. The only complete arthroplasty performed at Oliver General Hospital was in a patient with bony ankylosis of the elbow after an automobile accident. After prolonged hospitalization, he obtained painless motion from 60 to 140 degrees.

Arthrodesis of the elbow had not been performed at this hospital up to

the time this report was made, but three patients in this series would clearly require it when their wounds were healed. The position of fusion depended upon the arm involved and the occupation the man would follow after separation from service. For the right arm, in right-handed individuals, the best position was about 70 degrees, which made it possible to reach the face and head. For the left arm, with the right arm normal, the best position was 120 degrees. Each patient presented a different problem and was allowed to decide the position in which he wished his elbow to be used. Individual desires were followed whenever they were practical.

To complete the record, a small series of conservatively treated injuries of the radial head, reported by Capt. Baxter L. Clement, MC, from AAF personnel (*6*) is appended: All 10 patients were seen within 12 hours of injury.

> After sedation, the elbow was prepared by a careful sterile technique, as if for major surgery. Bony landmarks were identified, including the tip of the olecranon, the lateral condyle of the humerus, and the radial head. After the injection of Novocain (procaine hydrochloride) into the center of the triangle formed by these landmarks, an 18-gage needle was introduced into the joint at the same point. Continuous aspiration was maintained during its introduction and until blood was encountered. In each of these cases, there was immediate relief of pain and a considerable increase in the range of motion after the aspiration of 8 to 15 cubic centimeters of fresh blood.
>
> The patient was kept in bed, with the arm on a pillow in the position of greatest individual comfort (usually about 90 degrees of flexion, midway between supination and pronation), and ice bags were applied to the elbow for 12 hours. Active motion was then begun, and 30-minute whirlpool baths were given daily. During treatment, the patient was directed and encouraged to flex, extend, supinate, and pronate the elbow and forearm. Passive manipulations and massage were begun after the fourth day.

End results were excellent in all 10 patients treated by this method. Six returned to full duty within 14 days and the other four, within 20 days. During the 4 to 10 months they were followed, none of them experienced pain, instability, anatomic deformity, loss of function, or any other disturbance of the carrying angle.

OTHER TECHNICAL CONSIDERATIONS

Certain points brought out at the 1943 AAF conferences in the discussion of injuries of the elbow joint, which were then chiefly of the civilian type, are worth mentioning (*1*):

Dislocations.—The most popular method of managing dislocations of the elbow was immobilization in an elbow sling for 2 to 3 weeks, followed by active motion. Mention was made of two casualties received from overseas with previously unrecognized posterior dislocations. Another unusual case was reported, the combination of a posterior dislocation of the elbow and a fracture of the olecranon. The injury was followed by an excessive amount of extra-articular bone formation, which completely disappeared

with splinting and rest. Colonel Shands had also observed the complete disappearance of large masses of abnormal calcification in muscles and about joints after immobilization in plaster for 8 to 12 weeks and strongly recommended the method if such large calcifications occurred after dislocation of the elbow joint.

Excision of bone fragments.—There was considerable discussion concerning the advisability of removing comminuted fragments in fractures of the olecranon. Some surgeons advocated removal of all the proximal fragments. Others advocated removal of only the smaller fragments, followed by careful reapproximation of the tendinous structures of the triceps tendon and the use of a screw to maintain approximation of the principal fragments to the shaft. It was concluded:

1. That it was dangerous to remove too many fragments of the olecranon following a comminuted fracture.
2. That there was no warrant for complete excision of the injured olecranon process, as some surgeons were then advocating.

Monteggia's fracture.—Monteggia's fracture (a fracture of the upper third of the shaft of the ulna combined with an anterior dislocation of the head of the radius) was discussed at most of the 1943 AAF conferences, though only a few cases were reported. Several methods of management were proposed:

1. Fixation of the ulnar fracture by insertion of a Steinmann's pin through the olecranon into the shaft of the ulna and across the fracture line into the lower fragment. The proponent of this technique believed that reduction of the dislocated head of the radius could be maintained by flexion of the elbow after fixation of the ulnar fracture.
2. Fixation of the ulnar fracture by insertion of a Steinmann's pin followed by excision of the radial head.
3. Plating of the fractured ulna and construction of a fascial sling to hold the head of the radius in position.
4. Plating of the ulna and repair of the orbicular fragment of the neck of the radius.

There were no reports on end results of any of these techniques, and in his critique of the conferences, Colonel Shands made the following comments on them:

1. Construction of a fascial sling and repair of the orbicular ligament to hold the dislocated end of the radius in position are difficult surgical procedures, which should be undertaken only by trained and experienced surgeons.
2. Excision of the dislocated radial head is indicated if reduction cannot be maintained otherwise, but it should not be part of the primary procedure.
3. Open operation with plating of the ulnar fracture is always preferable to external fixation with a Steinmann's pin.[1]

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[1] It is possible that the recommendation for the use of the Steinmann's pin in this type of fracture is the earliest mention of intramedullary fixation of fractures in the United States.—M. C.

Manipulation of the elbow.—Manipulation of the elbow to expedite restoration of function was discussed at the 1943 AAF conferences, but the point was invariably made that under no circumstances should such manipulations be permitted after fractures and dislocations. Several tragic examples of this practice were recorded. Many orthopedic surgeons considered that passive stretching, carrying weights, and hanging by the arms from bars were also contraindicated. The additional injury sustained in this fashion could result in permanent decrease of mobility rather than an increase. The occasional good results obtained by these methods did not ever justify their use. It was far better to delay and let the patient carry out intensive active exercises himself at the proper time. If there was actual fixation of the structures by scar tissue, then, of course, surgery was necessary before active motion was possible.

SIDESWIPE FRACTURES

At any Army hospital in World War II, noncombat injuries among military patients resembled those incurred in civilian life, as would be expected because the mechanization of the war machine was similar to (though it exceeded) the mechanization of civilian life. It was not surprising, therefore, to encounter the civilian type of injury variously termed "car-window elbow," "driver's seat fracture," "traffic elbow," or "sideswipe fracture" represented in admissions and displaying the same characteristics this injury presented in civilian life. It was not a line-of-duty injury; in fact, it most often occurred while the soldier was on furlough, leave, or pass. It always occurred by the same (readily preventable) mechanism. It might range from no more than a few scratches to a most serious and disabling injury, for which amputation was often inevitable. It frequently consisted of compound fractures of all the bones comprising the elbow, an avulsive loss of soft tissue, and tearing of the vessels and nerves.

Analysis of Cases

The data from seven cases of sideswipe fracture reported by Lt. (later Capt.) LaRue S. Highsmith, MC, and Maj. George S. Phalen, MC, from O'Reilly General Hospital, Springfield, Mo., may be taken as a cross section, etiologically, pathologically, and therapeutically, of similar injuries all over the country (*7*).

When the injury occurred, all of the patients were riding with their elbows out of the window by the driver's seat. Of the seven, two were struck by other cars, four by trucks, and one by a bus. Several were in shock, which in one instance was severe, when they were admitted to the hospital. In two cases, primary amputation was performed through the lower third of the humerus, and in two others, the damage was so severe that the surgeons

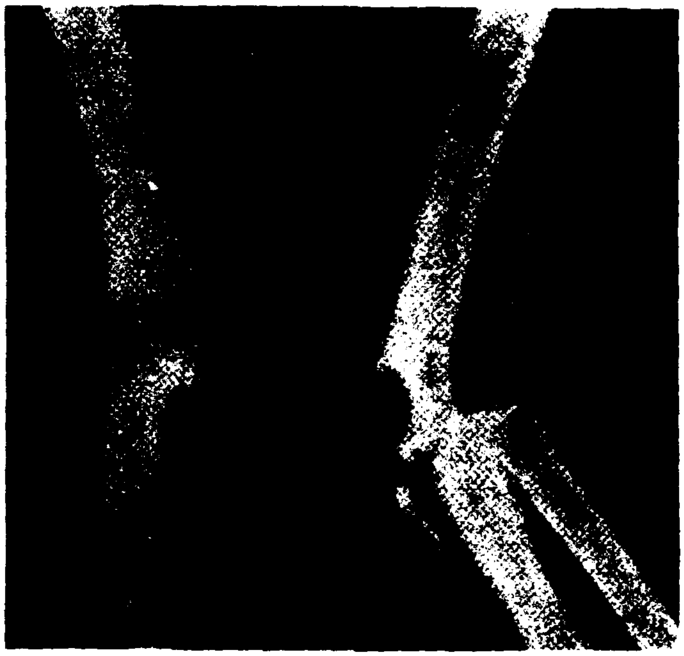

FIGURE 136.—Sideswipe fracture of left elbow. Anteroposterior and lateral roentgenograms of elbow 4 months after injury, showing obvious dislocation of joint, with loss of major portion of lateral humeral condyle and nonunion of small remaining fragment of olecranon process of ulna. This soldier had a very fortunate result; in spite of the marked disorganization of the joint, he had a satisfactory range of painless motion. (Highsmith, LaR. S., and Phalen, G. S.: Arch. Surg. 52: 513–522, May 1946.)

could not have been criticized if they had resorted to it at once instead of performing reconstructive surgery later.

Draining sinuses developed in one case, and in another, a gas bacillus infection threatened, for a time, to require amputation. Nonunion occurred in three *supracondylar fractures* of the humerus. In two, pseudoarthrodesis permitted a fairly useful range of painless motion. In the third case, a bone graft was planned, to be carried out with arthrodesis. These poor results were, unfortunately, entirely characteristic of this injury, which practically always, if primary amputation could be avoided, entailed several operations, a long period of hospitalization, and usually the loss of the man to service.

Management

Because of the multiple and widely various injuries that made up the total picture of sideswipe fractures (figs. 136 and 137), a standard routine of treatment could not be established, but in general:

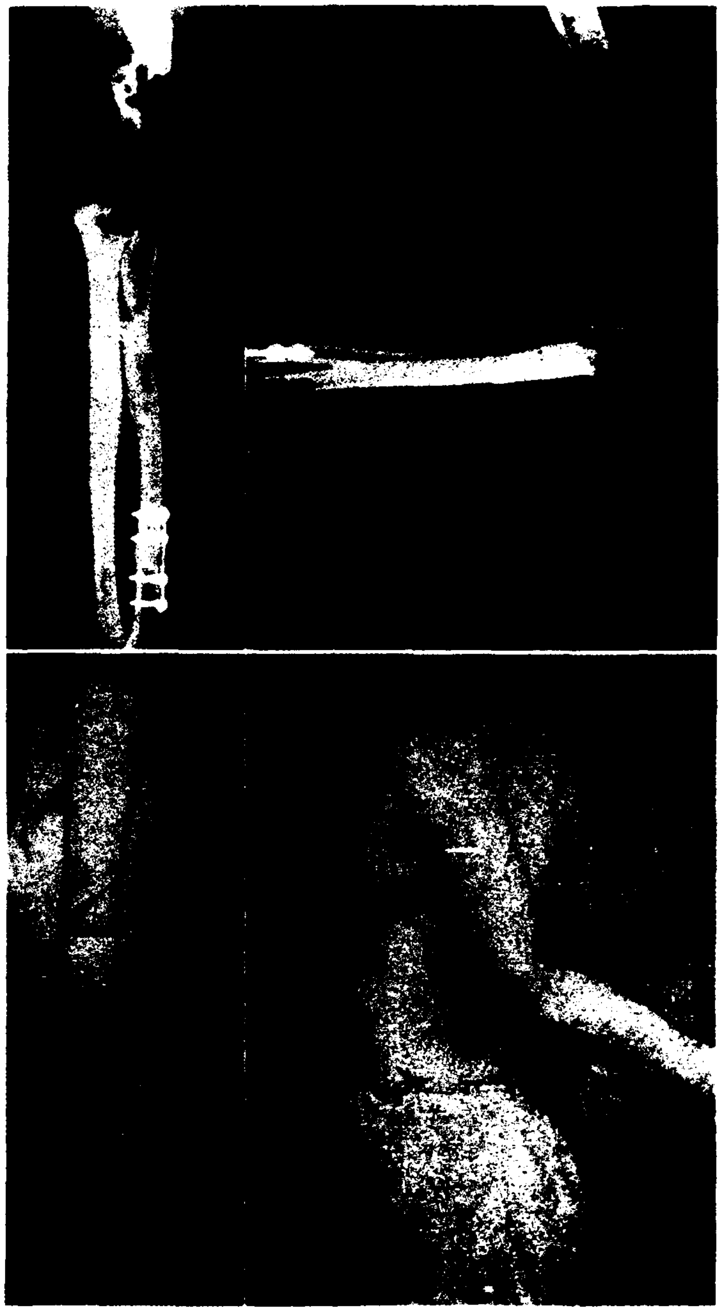

FIGURE 137.—Sideswipe fracture of left elbow. (Top) Anteroposterior and lateral roentgenograms of left elbow joint 10 months after this soldier had sustained a devastating sideswipe fracture. The entire joint, including the olecranon process of the ulna and the distal 5 inches of the humerus, had to be removed at the initial debridement. There was no peripheral nerve injury in this case. (Bottom) Photographs of soldier showing healed pedicle graft applied to posterior elbow region and healed donor site. Bottom right, showing hyperextension of elbow to 50 degrees, gives an indication of the extreme instability of this joint. With nerves and musculature intact, the question of arthrodesis was probably under consideration. (Highsmith, LaR. S., and Phalen, G. S.: Arch. Surg. 52: 513–522, May 1946.)

1. Debridement was performed, with removal of foreign bodies and of detached fragments of bone.

2. Nerves were sutured primarily if they were disrupted and were readily visualized.

3. Sympathetic cervical blocks were instituted if the circulation in the extremity was impaired.

4. If the circulation was impaired to such a degree that ligation of the brachial vessels would be necessary, or if those vessels were thrombosed, amputation was usually a procedure of necessity, though every effort, of course, was made to preserve the extremity, on the ground that even a poorly functioning hand was superior to a prosthesis.

Amputation was usually done at the level of the fracture site in the supracondylar region of the humerus. Primary amputation was done in one of the sideswipe fractures at O'Reilly General Hospital because there was adequate skin to cover the stump without tension. The result was good, but the procedure was in violation of established Army policy, which was to perform open circular amputation, institute skin traction, and close the stump or reamputate at a higher level, as indicated, after all risk of spreading infection had disappeared.

5. Major bone fragments were approximated as well as possible and maintained by external immobilization, in a plaster cast extending from the axilla to the metacarpal phalangeal joints, with the forearm in neutral position of rotation and the elbow flexed at 90 degrees. If there was evidence, or suspicion, of vascular involvement, the cast was bivalved and only the posterior shell was used until the difficulty had disappeared.

Fractures of the forearm could be reduced by skeletal traction or by transfixing wires incorporated in the cast. Internal fixation was seldom feasible in comminuted fractures extending into the elbow joint.

Fractures immediately about the elbow could be immobilized adequately by a plaster cast. Since ankylosis of the joint was usually inevitable, the forearm was best put up at a right angle to the upper arm.[2] If this position produced constriction of the brachial vessels, the forearm was extended as necessary for a few days, to permit swelling in it to recede.

6. Immediate resection of the entire damaged joint, or at least of the comminuted fractures composing the distal end of the humerus, was done in one of the seven sideswipe fractures at O'Reilly General Hospital and was considered the procedure of choice by some orthopedic surgeons. It was regarded as a better plan, at the time of debridement, to remove only completely detached bone fragments, which were certain to sequestrate, and to perform resection later, if it was still thought to be indicated when the precise level for it could be more carefully chosen.

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[2] The optimum angle of fixation for an arthrodesis of the elbow joint is 90 degrees, which is a right angle. As pointed out elsewhere, if the patient is a laborer, the proper position is 120 degrees, or 30 degrees beyond the right angle. The 90-degree position is for office workers.—M. C.

FIGURE 138.—Lateral roentgenogram showing compound comminuted fractures of lower humerus, radius, and ulna due to shell wound after most of missing bone had been removed at debridement overseas. Infection with osteomyelitis supervened, but the wounds are healed at this time. Several metallic foreign bodies are evident. Arthrodesis at the elbow was planned. (McDowell, H. C.: Fractures About the Elbow. [Unpublished data.])

7. Arthroplasty was sometimes possible, instead of the resection originally thought inevitable, after fractures had healed. At any rate, a more stable and more useful joint resulted if too much bone was not removed. Arthrodesis was also difficult if too much bone was removed originally. This operation might be indicated later, particularly if the patient had to make his living by doing manual labor.

8. Skin grafts were frequently required because of the extensive damage to the skin overlying the posterior aspect of the elbow. A pedicle graft from the abdomen was sometimes necessary instead of a split-thickness graft, if further surgery was contemplated.

Note.—Injuries about the elbow related to special features of training are discussed in the chapter on training injuries (p. 227).

Section II. Combat-Incurred Injuries

The whole story of combat-incurred injuries about the elbow as they were handled in Zone of Interior hospitals is encompassed in the experiences of the following general hospitals (figs. 138–143).

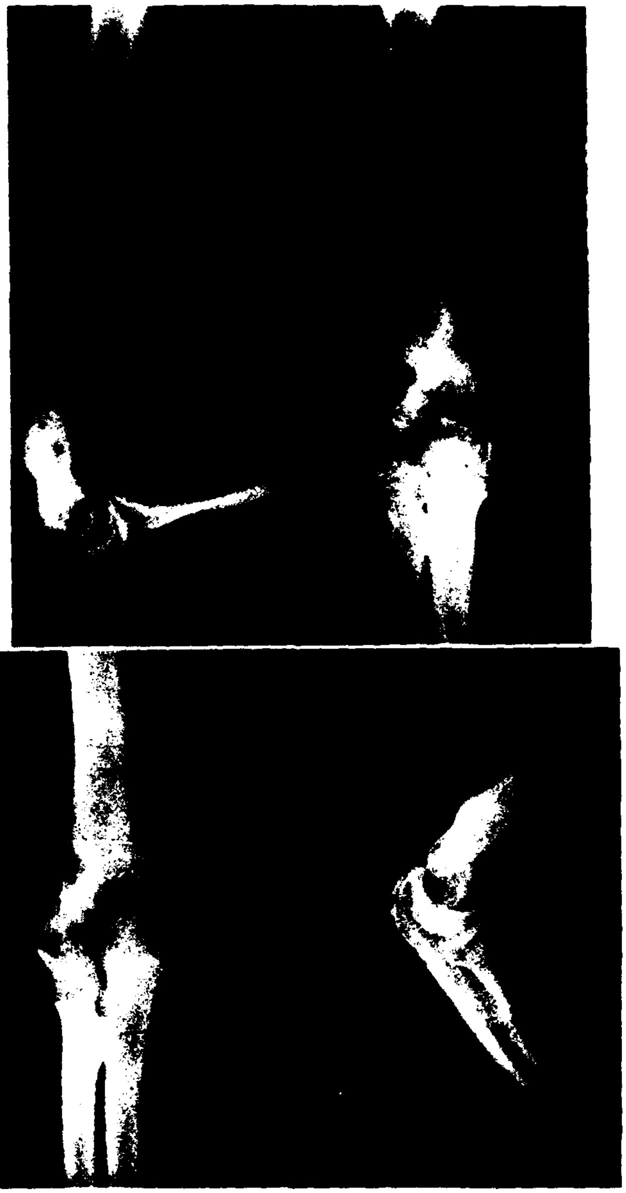

FIGURE 139.—Management of gunshot fractures of elbow. (Top) Lateral and anteroposterior roentgenograms of right elbow showing healed comminuted fractures of lower humerus. Only 5 degrees of motion from 95 to 100 degrees was possible. (Bottom) Anteroposterior and lateral roentgenograms of same elbow after partial resection of joint. Though he was still convalescent, this officer had an active range of motion from flexion at 75 degrees to extension at 140 degrees. Passive motion was possible from 65-degree flexion to 165-degree extension. Pronation and supination were normal. (McDowell, H. C.: Fractures About the Elbow. [Unpublished data.])

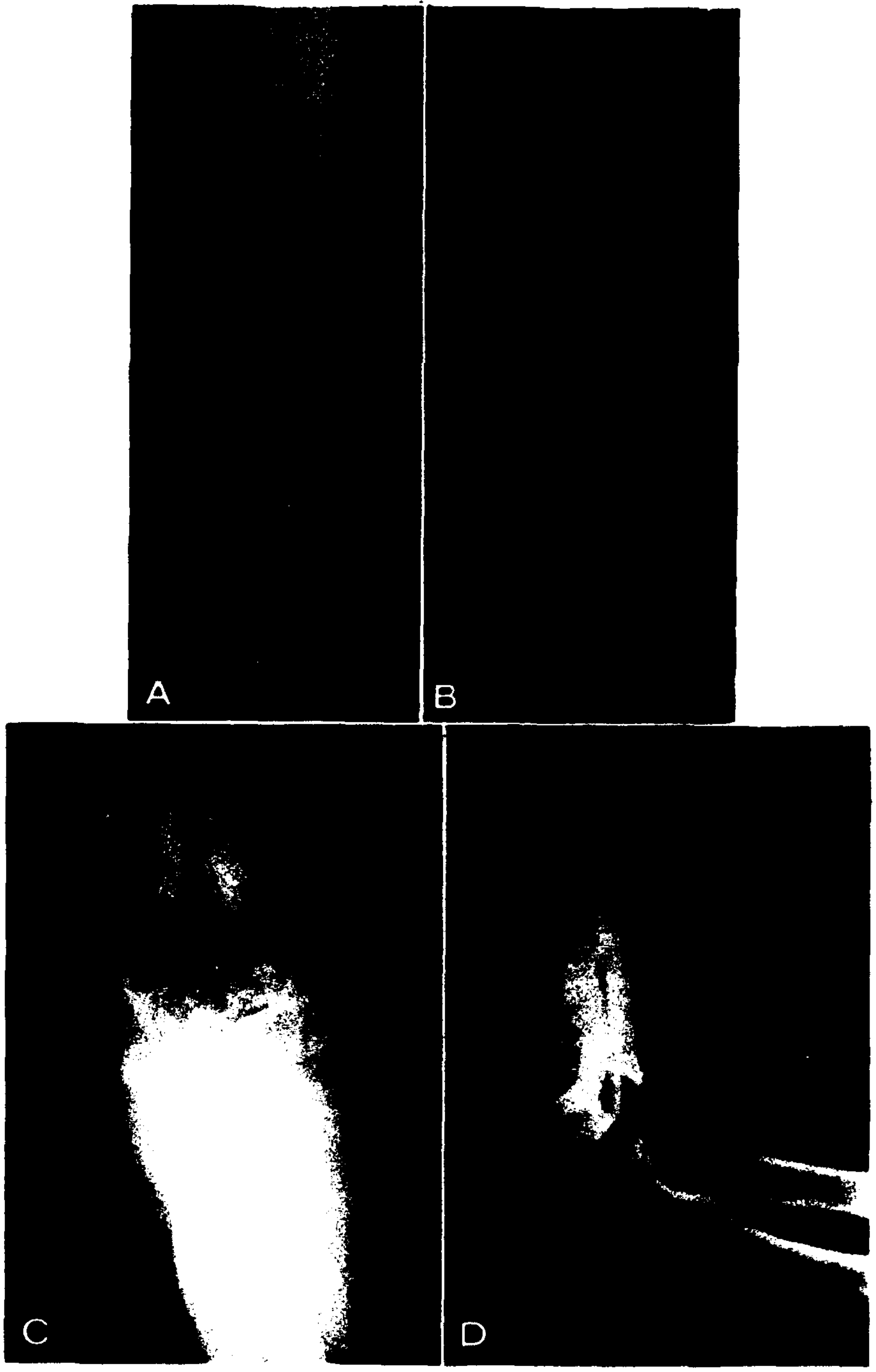

FIGURE 140.—*Management of gunshot fractures of elbow.* A and B. Lateral and anteroposterior roentgenograms of elbow joint showing severely comminuted fractures of lower humerus and olecranon process of ulna. There was a fibrous ankylosis of the elbow at 100 degrees. C and D. Lateral and anteroposterior roentgenograms of same elbow after repair of triceps tendon and partial resection of elbow joint. Active motion was secured from 65-degree flexion to 154-degree extension. (McDowell, H. C.: Fractures About the Elbow. [Unpublished data.])

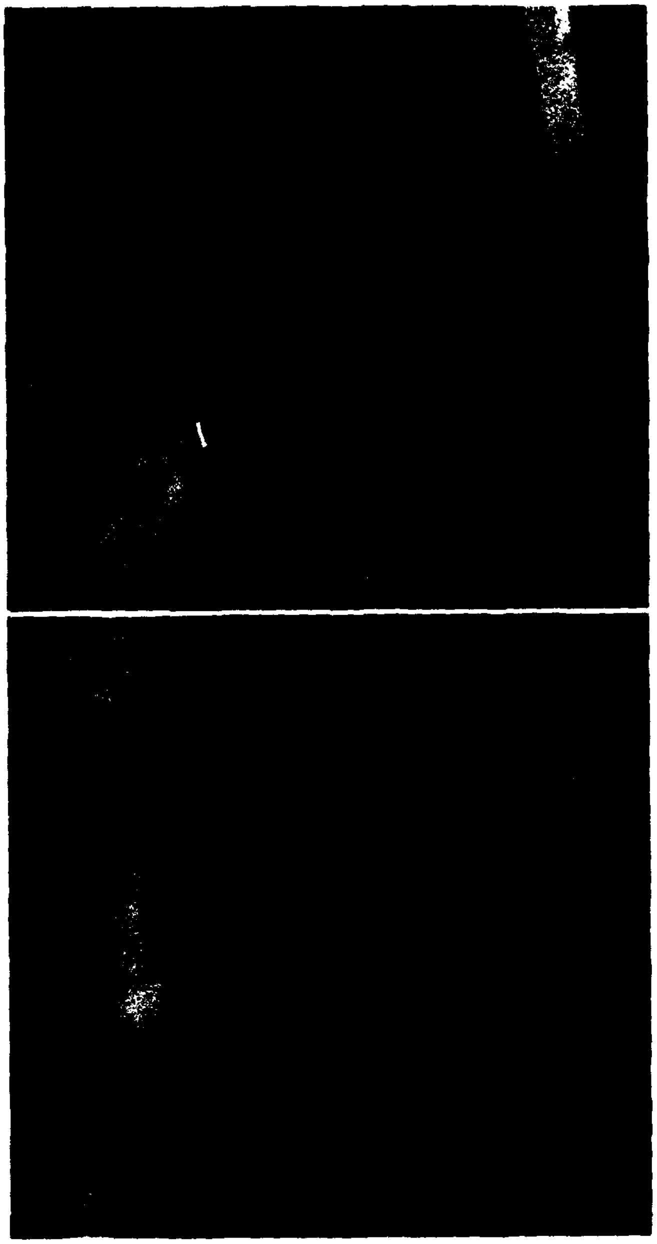

FIGURE 141.—Shattering compound comminuted fracture of right elbow joint caused by mortar shell fragments, with ankylosis permitted in position best suited to needs of soldier. (Top) Anteroposterior and lateral roentgenograms showing extreme comminution of distal humerus and proximal radius and ulna. There were massive soft-tissue wounds. (Bottom) Lateral and somewhat oblique roentgenograms 9½ months after injury. The elbow was spontaneously ankylosed at 125 degrees, the position desired by the patient, who was a farmer in civilian life. In spite of severe muscle damage, his finger motion was about half of normal.

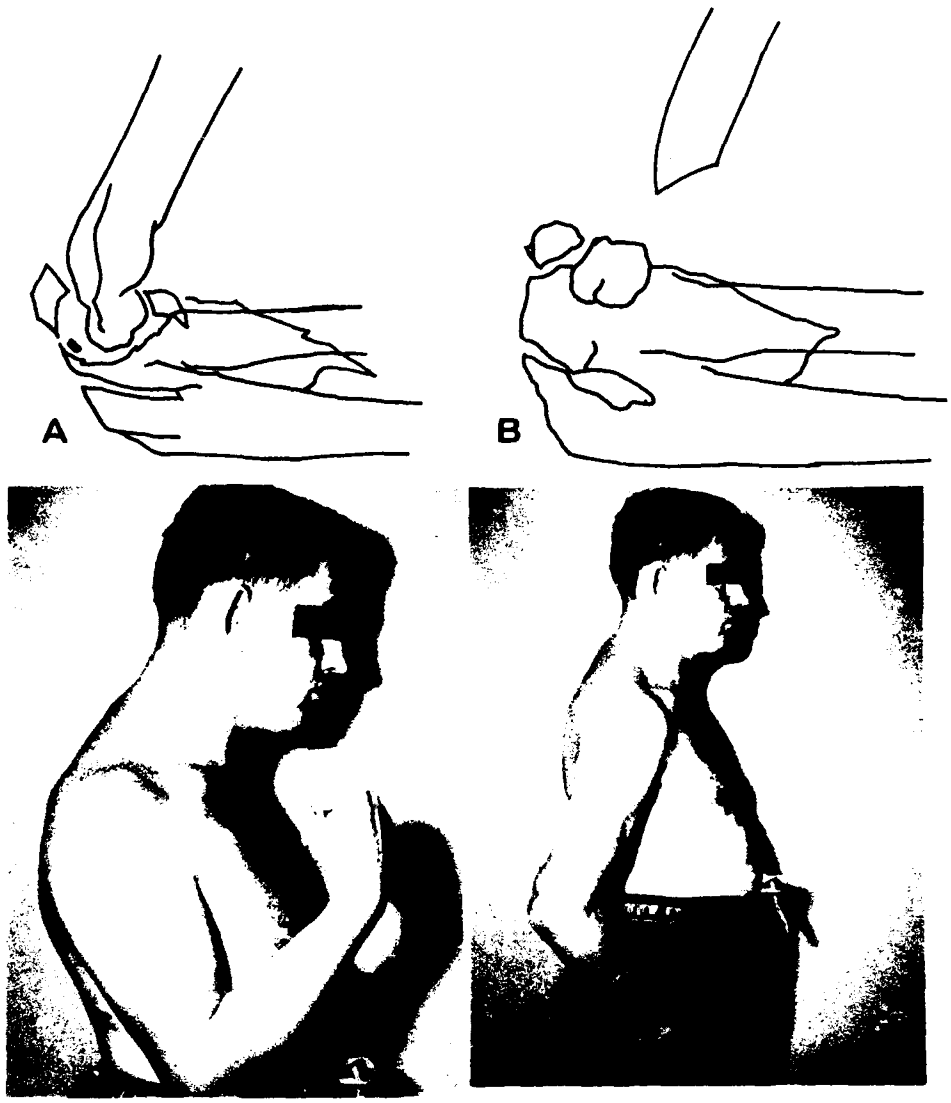

FIGURE 142.—Reconstruction of elbow joint after extensive gunshot fractures. A. Tracing of lateral roentgenogram of right elbow with gunshot fractures of humerus, radius, and ulna, and almost complete loss of olecranon process. There was no motion in the elbow. B. Tracing of lateral roentgenogram 3 days after reconstruction operation, at which lower end of humerus was transected at level of sigmoid notch. The lower fragment was left in the notch. The upper humeral fragment was trimmed to a knifelike edge and covered with a fascial cap. C and D. Photographs of soldier 10 weeks after operation described, showing range of motion in right elbow from flexion at 70 degrees to extension at about 130 degrees. (Parnall, E.: J. Bone & Joint Surg. 30A: 752–756, July 1948.)

FIGURE 143.—Spontaneous fusion of elbow joint after compound comminuted fractures sustained at Okinawa on 8 April 1945. The patient had prompt first aid and debridement the day of wounding. Sequestrectomy was performed on 10 October 1945 and a foreign body was removed. Anteroposterior and lateral roentgenograms of elbow showing fusion at 130 degrees. Note metallic foreign bodies still in situ. This casualty was left with a strong arm and painless function.

VALLEY FORGE GENERAL HOSPITAL

Principles of Management

On the well-organized fracture service at Valley Forge General Hospital, Phoenixville, Pa., combat-incurred injuries about the elbow as well as other injuries were managed with the idea of achieving certain functional objectives (*8*):

1. Strength. To accomplish this objective in both forearm and hand, a fixed elbow was regarded as far better than a painful or a flail elbow.

2. Range of motion. If an elbow had to become fixed, the degree of fixation was related, as far as possible, to the patient's work. An elbow fixed at an angle of 110–120 degrees was most useful to a man who did heavy work. A slightly sharper angle was more useful for office work. If full rotation was present, the actual disability was confined chiefly to dressing and eat-

ing. A range of flexion and extension from 70 to 150 degrees provided a really serviceable elbow.

3. Stability. This factor had to be analyzed with great care. Certain components of the normal elbow structure, such as the olecranon, the coronoid, the lateral condyle, and the radial head, could be lost or removed without serious effects on function. When, however, all the components of the mechanism of the joint were destroyed, the situation was entirely different. A flail joint was not the solution; it was awkward and it lacked strength. A severely mutilated joint that was not painful could be surprisingly useful if its hinge action was well enough in line and sufficiently supported to permit the proper pull of the biceps and triceps mechanism. Before any decision concerning therapy was arrived at, bony relations had to be carefully analyzed. Roentgenograms of injured elbows are not easy to interpret, and multiple views were often necessary before the relation of the structures to each other became clear.

With these objectives, a plan of treatment was worked out for the individual patient, based on his special needs, but including the following procedures:

1. Most patients were received from overseas in plaster casts, which were highly effective for transportation in that they provided rest for the injured parts, support for the vascular supply, and control of the bone fragments. If the wound was deep and bony instability evident, immobilization in casts was maintained, but no longer than was absolutely necessary, partly because early mobilization of the elbow was highly desirable and partly because soft-tissue healing takes place faster outside of plaster.
2. Sequestra causing persistent sinuses were searched for and excised.
3. Exposed bone was trimmed back, so that granulations would grow over it.
4. With these exceptions, all surgery was delayed until the risk of infection had passed and all active tissue reaction had subsided. Too early surgery, even after penicillin became available, introduced the risk of active infection, proliferation of fibrous tissue, thickening of the capsule, and progressive myositis ossificans.
5. Followup physical and occupational therapy was necessary for good end results.

Routine of Examination

The initial examination of the patient with an injured elbow concentrated on the following points:

1. Circulatory complications, which were infrequent at this stage of the injury, but which could be extremely serious. In two of the three cases in which they occurred at O'Reilly General Hospital, severe contractures of the hand and wrist, with ischemia, resulted.

2. Nerve involvement. If any paralysis existed, the motor and sensory responses of the ulnar, median, and radial nerves were tested. They were frequently involved, either singly or in combination, in shattering compound fractures about the elbow.

3. Muscle involvement. Although partial tears of many of the regional

muscles were frequent, they were serious only occasionally in the injuries treated at Valley Forge General Hospital. In one case, the bicipital tubercle was torn away, and with it, the insertion of the biceps.

4. Damage to the joint. In all elbow injuries, it was important to think (and for the inexperienced medical officer to learn to think) not in terms of fractures of individual bones, but in terms of the total disorganized, comminuted joint. Even in seemingly hopeless injuries, as already indicated, it was often amazing to see fragments of bone and periosteum coalesce and resolve into strong, healthy bone if they were properly supported and protected. The joint itself regained form and detail. In the final stages of healing, active use was permitted and encouraged, to determine the residual problems still to be overcome; such as, hinge action, rotation, missing fragments, distortions that caused blockage of flexion or extension, and nonunion. No matter what the injuries, experience showed that deliberate, conservative action produced the best end results.

Anatomic Reconstruction

At Valley Forge General Hospital, anatomic reconstruction of the elbow covered the following components:

The epicondyles.—The destruction of the epicondyles was not of major importance, since the damaged muscle origins generally reattached themselves to the nearest bone and continued to function efficiently. In some cases, regeneration was observed. Even bizarre extensions torn loose from the lateral condyle sometimes reattached themselves. Whenever these extensions seemed to interfere with function, they were removed, without any subsequent weakness of function.

The lateral condyle.—The most common type of severe fracture of the lateral condyle resulted in varying degrees of rotation and, usually, forward displacement of the capitulum humeri. When functional loss was limitation of flexion and extension because of blocking by the radial head, rotation was often nearly normal. If the flexion block was beyond 90 degrees, a decided gain in function often followed resection of the radial head. In some cases, the capitulum was reshaped by correction of the anterior deformity.

Case 1.—A soldier who was wounded in Italy in January 1944 by a machinegun bullet was observed at Valley Forge General Hospital in the final stage of bone healing. Although the lateral condyle and capitulum were completely absent, the elbow was strong and stable and the functional result was excellent. Rotation was complete. Flexion up to 75 degrees was possible, and extension was possible up to 140 degrees. Motion was painless. The extensors of the wrist and hand functioned normally, although no bony origin for the muscles could be demonstrated. It was assumed that the origins of the extensor muscles had attached themselves to the fascia and scar tissue leading to the shaft of the humerus.

After this patient had been observed, serious thought was given at Valley Forge General Hospital to the relative importance of the whole lateral condyle, and it was

concluded that, as long as enough of the trochlea remained to give stability to the swing of the olecranon, the lateral condyle apparently was not needed for satisfactory function. In this and similar cases, the completeness of rotation was noteworthy.

The internal condyle.—When the internal condyle was fractured, the results were very different from the results when the lateral condyle was fractured. The joint between the internal condyle and the olecranon might be so completely destroyed that, eventually spontaneous fusion would occur. When this outcome was anticipated, great care was necessary to preserve the joint angle, as the following case history shows:

Case 2.—A soldier who had been wounded in North Africa in March 1943 by machinegun fire arrived in the Zone of Interior with his shattered elbow in a cast. Sequestrectomy was performed in August 1943 and repeated the following month. Bone healing was finally complete in January 1944, but bony ankylosis had occurred between the olecranon and the trochlea. Nevertheless, although the olecranon was fixed, the man had a strong right arm, with normal rotation, and he intended to resume his former occupation as a groom.

In another case, even though considerable deformity was present, a fair amount of motion was preserved:

Case 3.—A soldier who was wounded in Italy in January 1944 by machinegun fire arrived in the Zone of Interior with comminution of the condyles. When healing was complete, rotation was normal, flexion from 70 to 135 degrees was possible, and the radial head remained free and rotated normally. Arthroplasty was under consideration, but from the standpoint of function, the result achieved was entirely satisfactory.

The olecranon.—The experience at Valley Forge General Hospital led to the conclusion that hinged action of the elbow was possible without the presence of very much of the olecranon as long as the triceps attachment was preserved. If it was, function and stability of the joint were satisfactory. If the fracture of the proximal olecranon was comminuted, it was advantageous to discard the fragments. In two cases, the bone was shortened considerably, and end results were good.

In a number of cases in which the olecranon was distorted and filled with callus, reshaping the fossa did not develop as much extension as had been hoped for, possibly because sufficient bone was not removed. In retrospect, it was concluded that, if the olecranon blocked extension, it would be well to consider shortening the proximal end by as much as a third to a half. If the triceps tendon was reattached after subperiosteal reflection, the joint would remain stable. Fragments of the coronoid process of the ulna could also be removed without the joint's slipping backward in extension.

The radial head.—A frequent result of comminution or displacement in fractures of the radial head was loss of full rotation. At Valley Forge General Hospital, resection of the head almost always provided 50 to 85 degrees of normal range.

Followup was not long enough in any of these cases to determine the incidence of painful radio-ulnar wrist joints after resection of the radial

head. In several painful joints resulting from other injuries, it was clear that removal of the distal end of the ulna would insure relief.[3]

The anterior capsule.—Block of the anterior capsule resulted from thickening and contracture of the capsule, with or without deposition of calcium or the presence of bone fragments from the coronoid process of the ulna or the head of the radius. The brachialis muscle was usually lacerated and had been replaced by fibrous tissue, or myositis ossificans had developed. These changes were rather frequent after the usual civilian-type dislocations of the elbow as well as after the severely comminuted fractures sustained in combat. The functional handicap, that is, loss of extension, could be corrected, after tissue reaction had quieted down, by resection of the anterior capsule, along with excision of scar tissue and bony masses. This procedure usually insured a reasonable degree of increased extension. An extension splint was worn for at least 3 weeks, and a night splint was used for a longer period, to prevent any tendency toward recurrence.

Case 4.—In a truck accident in Italy, in February 1944, a soldier sustained a dislocation of the elbow and a fracture of the head of the radius, which had been excised overseas. Myositis ossificans, scar tissue, and contraction of the anterior capsule restricted extension to 90 degrees. Flexion and rotation were practically complete. After anterior capsulotomy, the range of extension was 70 to 140 degrees, a gain of 50 degrees.

Synostoses.—Synostoses between the radius and ulna near the joint were infrequent; only three instances were observed at Valley Forge General Hospital. Resection of the bony bridges had to be carried out with great care and thoroughness, and recurrence could be expected unless soft tissue was interposed between the bones.

Case 5.—A soldier, struck by the propeller of a B–24 in Libya in June 1943, sustained a fracture of the ulna, and a synostosis developed between the ulna and the proximal radius. Excision of the bony bridge restored 75 percent of rotation.

Pseudoarthrosis.—This condition (supracondylar false joint) was associated with a weak, awkward motion of the elbow and hand:

Case 6.—A soldier wounded in Tunisia in March 1943 by shell fragments had a weak, unstable false joint in the supracondylar region after soft-tissue healing. Realinement with fibrous union added 10 degrees of motion to the 10-degree residual in the true joint, in which rotation was complete. The patient thus had a strong, stable arm. At operation, the old bone was removed and the fragments were replaced in relatively normal alinement and fixed with Kirschner wires. The hope of union was not achieved, probably because of the flareup of a low-grade infection, but the pseudoarthrodesis stabilized very well. The final result, which was preferable to a fixed joint, was complete and painless rotation, flexion from 90 to 110 degrees, and good strength.

Flail joint.—A satisfactory technique of handling a flail joint is well illustrated in the following case history:

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[3] The foregoing remarks refer only to the experience at Valley Forge General Hospital with management of the head of the radius in injuries about the elbow. The subject is discussed at greater length later in this chapter.

Case 7.—A soldier wounded in Tunisia by rifle fire in May 1943 arrived in the Zone of Interior with a blasted elbow and with the radial nerve gone. A flail joint was present after soft-tissue healing. He was first treated on the plastic surgery service by a full-thickness skin graft from the abdomen. Next, wrist flexors were transferred into the extensors of the thumb and fingers. Reposition of the three bone ends was carried out, with the intention of fusion. At a final operation, about an inch of the proximal radius was resected, to permit rotation. The result of these procedures was a strong, stable elbow, with motion from 100 to 120 degrees and 70-degree rotation. The hand was strong and useful, with a full range of motion.

It should be noted that the flexor group of forearm muscles functioned with excellent strength in this case, even though both condyles of the humerus were missing.

Instability from nonunion of proximal ulna.—Disruption of ulnar continuity near the joint inevitably resulted in instability: The radius serves as a guide in flexion and extension, but when the ulna is missing, it simply acts as a pivot on which the forearm rotates laterally. Three such cases, of which the following history is an illustration, were observed at Valley Forge General Hospital:

Case 8.—A soldier who was wounded in Sicily in July 1943 by machinegun fire had a defect in the ulna, with angulation and rotation of the olecranon. Before a bone graft could be attempted, a series of casts had to be used to realine the olecranon with the rest of the shaft of the ulna. The deep scar over the upper ulna was completely excised and the area was covered by a free split-thickness local flap. The residual scar was then covered by a free split-thickness graft from the thigh. This work was done on the plastic service. When it was completed, a graft from the fibula was applied to the ulna. The proximal end was doweled and fitted by the intramedullary technique. The distal end was stepped against the shaft and held by two screws, with nuts and washers.

Nerve involvement.—Fractures of the elbow associated with nerve involvement are treated in detail in the neurosurgical volumes (*9, 10*), particularly the second volume, in the series dealing with the history of the U.S. Army Medical Department in World War II.

Ischemic contractures.—At Valley Forge General Hospital, Volkmann's ischemic contracture was an infrequent outcome of injuries about the elbow. In established cases, surgery was sometimes useful:

Case 9.—In Algiers, in June 1943, a soldier was wounded by a missile fragment. Injury to the brachial artery resulted in a severe contracture of the wrist and hand. There was no improvement after months of painstaking stretching and training of the fingers and wrist. Carpectomy, with arthrodesis from the radius to the metacarpus, put the hand into a good grasping position and left the tendons sufficiently loose to permit the fullest possible use of the little strength that remained in the badly damaged muscles.

A similar result was obtained in another patient who presented the same problem.

ASHFORD GENERAL HOSPITAL

Paralysis or destruction of all the muscles responsible for flexing and extending the elbow was sometimes encountered in combat wounds and was

dealt with on an individual basis (*11*). If the patient did manual labor, arthrodesis was the operation of choice. When there was less need for power, flexion was restored by the Bunnell modification of Steindler's operation for transplantation of the origins of the forearm flexors (*12*). To use this operation, however, it was necessary that the range of passive motion be good before operation. The procedure was used only once at Ashford General Hospital, White Sulphur Springs, W. Va., in a case in which the important humeral head of the pronator teres was found destroyed. Although the operation was not performed too well technically, 95 degrees of complete range of elbow motion resulted. Eight months after operation, the patient was able to lift a 4-pound weight through the entire arc of motion of the affected joint. The new origin of the forearm flexors was made laterally, as advocated by Bunnell, and supination was not impaired.

The experience at this hospital corresponded with the general experience that the elbow lends itself well to arthroplasty as would be expected. It is a non-weight-bearing joint and does not have motion in all directions as the shoulder does, which means that stability is more easily attained.

Resection of the elbow joint for traumatic disability was not practiced at Ashford General Hospital, on the ground that the resulting loss of joint stability rendered effective use of the hand difficult and might constitute an accident hazard. Arthrodesis by some means was practically always possible, and painless motion and good function could be anticipated after it, especially if fusion could be confined to the humero-ulnar joint, with rotation of the forearm left free.

If arthrodesis was really impossible, conservative measures, especially supervised active use, often restored economically useful function to a severely damaged elbow.

Injuries to the elbow sometimes resulted in disability out of all proportion to their apparent severity, and vice versa. The best plan was to observe the patients after the fractures had healed before deciding upon their management. If progress occurred with active exercises, it could be expected that progressive improvement in function would occur with the passage of time, and surgery was, therefore, withheld.

Flexion contractures following fractures responded favorably to capsulotomy by the Wilson technique. Except for reconstruction of the annular ligament in Monteggia's fractures by the Campbell technique, attempts seldom were made at Ashford General Hospital to reconstruct the ligaments of the elbow.

MOORE GENERAL HOSPITAL

At Moore General Hospital, Swannanoa, N.C., Lt. Col. Edward Parnall, MC, developed a new approach for reconstruction of the elbow joint (*13*):

The elbow was approached at its medial aspect through a curved longitudinal incision 4 to 5 inches long, the apex of which fell just short of the tip of the medial epicondyle. The ulnar nerve was exposed throughout the length of the incision, freed up, and retracted. The medial epicondyle was then divided cleanly with an osteotome and retracted medially, along with the attached flexor muscle in the forearm. The elbow was exposed by sharp dissection of soft tissues from the periosteum.

From this point, the procedure depended upon the case in question. In the five cases in which this technique was used at Moore General Hospital—

1. A standard arthroplasty was performed, with interposition of a sheath of fascia.
2. A malformed humeral condyle with fibrous ankylosis was removed, and the lower end of the humerus was trimmed to a knife edge without fascia.
3. The lower fragments of an un-united fracture of the humerus were removed.
4. Overgrown fragments of bone that were blocking motion were removed.
5. The humerus was divided just above the trochlea, trimmed to a knife edge, and covered with fascia. The trochlea was left in the remains of the olecranon fossa, as the olecranon process in this case had been almost completely destroyed.

When the special procedures indicated in each case had been carried out, the flexor muscle mass was sutured back in place, usually after the fragment of the medial epicondyle had been excised. The ulnar nerve was transposed anteriorly and the skin sutured.

The cast applied, from palmar crease to axilla, with the elbow at a right angle, was used merely for immediate postoperative stability. It was discarded within the week. As soon as the patient had recovered from anesthesia, he was encouraged to contract the triceps and biceps muscles simultaneously, to improve their tone and to snug the newly arranged elbow joint. After the cast was removed, he was encouraged to move the elbow actively in a gradually increasing arc.

While there is no followup on these patients, the immediate results were highly encouraging; early and rapidly increasing motion was possible, and a stable elbow was secured in four of the five cases.

The single disadvantage of this technique, in Colonel Parnall's opinion, was that it was more complicated than the standard posterior incision. It did not, however, divide the triceps tendon, which made earlier motion possible, and it did not require periosteal stripping, which always reduced the proliferation of new bone.

NEWTON D. BAKER GENERAL HOSPITAL

In military surgery, practically all stiffened elbows follow gunshot fractures, which, in many instances, are complicated by infection. Scars over the area are often so large that before arthroplasty is possible, they must be resected and replaced by full-thickness skin grafts from the abdomen. In contrast to civilian surgery, in which arthroplasty is usually done on uninfected joints partly or completely ankylosed by arthritis, the opera-

tion in military practice must be deferred until it is certain that the risk of infection has disappeared.

In 10 arthroplasties for combat-incurred injuries of the elbow performed at Newton D. Baker General Hospital, Martinsburg, W. Va., in 1944–45, the following technique was employed (*14*):

An incision 8 to 10 inches long was made in the midline of the elbow posteriorly and was carried down to the bone. The soft tissues were reflected from the humerus and ulna. The ulnar nerve was dissected out and retracted. The ankylosis was usually created between the humerus and the ulna. A V-shaped piece of bone, with arms 1 inch wide, was made with the point proximally. The olecranon was chiseled down and coronoid process of the ulna was completely removed. The head of the radius also was completely removed and the neck was smoothed off. At this point of the procedure, a large space existed between the radius and the ulna, and motion was possible in all directions.

A piece of fascia, usually measuring from 4 to 8 inches, was removed from the opposite thigh and was used to line the joint, with its internal aspect next to the bone. The fascia was fixed to the soft tissues of the anterior aspect of the joint by two catgut sutures. A double layer of fascia was thus provided over the olecranon and the humerus. The edges of the fascia were sutured to the surrounding soft tissues. The skin was closed with silk.

The elbow was placed in anterior and posterior plaster splints extending from the knuckles to the shoulder, with the forearm in neutral position. In two of these 10 cases, the patients preferred that the elbow be put up at an angle of 135 degrees, which they thought would be more useful to them. In the other eight cases, it was put up at a 90-degree angle.

The sutures were removed in 10 days, and physical therapy was begun 3 weeks after operation. Motion usually was regained rapidly, and maximum ability was attained in 3 or 4 months.

Because of the special circumstances in these cases, the usual criteria of success were somewhat modified:

1. Four results were considered excellent because of the improvement accomplished. In the first case, anteroposterior motion within 5 months of operation was 80 degrees and rotation 50 degrees. This man could now lift his hand to his face and to the back of his head. In the second case, anteroposterior motion was 130 degrees and rotation was normal within 7 months. In the third case, anteroposterior motion was 75 degrees and supination was 60 degrees within 2½ months, but this patient had no pronation beyond the mid position.

In the fourth case in this group, an infection developed that threatened to wreck the results, but it cleared up, and within 5 months, the patient had 130-degree anteroposterior motion and 40-degree rotation. The arm was very useful when it was dependent, but he had little control over it when the shoulder was abducted 90 degrees. The result, however, was a great boon to the patient, for the other arm was paralyzed, and it was now possible for him to feed himself and to hold a cane when he walked.

2. Three results were considered good. The first patient had 55 degrees of anteroposterior motion in 3 months, after control of a postoperative infection. The second patient had 40-degree active and 60-degree passive motion in 3½ months, and the third had 30 degrees, of anteroposterior motion in 5 months.

3. Three operations were followed by uncontrollable infection. In two of these cases, ankylosis at an angle of 90 degrees resulted. In the third case, the wound was still draining when the patient was last seen, but it was hoped that some degree of motion might be salvaged. As these three cases show, infection is a complication of

arthroplasty greatly to be feared, though it usually subsides and leaves the elbow in its original condition, with no real loss.

The seven successful, or partly successful, cases in this series are thought to demonstrate the value of arthroplasty. The resulting shoulders were never so strong as normal joints. The patients could not lift heavy weights or do any sort of heavy work because the joints lacked stability. For the same reason, the usefulness of the forearm was much less with the shoulder abducted than with the arm at the side. It was a great deal, however, for a previously helpless patient to get his hand to his face, shave himself, feed himself, and do many other things he could not previously do for himself.

It was believed originally that the more solid the ankylosis before operation, the better the results of arthroplasty, but in the most successful case in this series, 30 degrees of anteroposterior motion was present before operation. It was the practice at the Newton D. Baker General Hospital to massage the scar provocatively for a week before operation, to make sure that surgery would not light up a latent infection.

Arthroplasty of the elbow by replacement of the distal portion of the humerus with an acrylic prosthesis was chiefly a postwar development at O'Reilly General Hospital (*15*).

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CHAPTER XIX

Injuries of the Forearm and Wrist

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Section I. Noncombat Injuries

GENERAL CONSIDERATIONS

Management of noncombat fractures of the bones of the forearm in military service did not differ materially from their management in civilian practice.

The ulna usually could be reduced without much difficulty, as this is a subcutaneous bone and not hard to palpate. The radius presented more serious problems, chiefly because of its muscular attachments, most particularly the pronator teres. In the upper half of the radius—that is, above the attachment of this muscle—supination of the forearm and flexion at the elbow usually brought the fragments into line. In fractures of the radius below the insertion of the pronator teres, the lower fragment could be alined with the forearm in mid pronation-supination, since the actions of the supinator and pronator apparatus are about balanced. Once the fragments were thus alined, the application of traction to the hand, and particularly to the thumb, ordinarily permitted the fragments to be maneuvered into position digitally.

An important point to be borne in mind in all fractures of the lower part of the forearm was that the pronator quadratus, the supinator longus, and the extensors and abductors of the thumb tend to obliterate the interosseous space between the distal fragments of the radius and ulna. This situation could be corrected by the use of manual pressure to interpose soft tissue between the bones. If a cast was applied, great care was taken to avoid pressure that would force the radius and ulna together; otherwise, angulation into the interosseous space would result, and synostosis between the bones would become a real danger.

Open reduction was the only solution in many fractures, but before resorting to it, the surgeon had to remind himself that, although good alinement of the bones was essential in the management of these injuries, hairline reduction was not. Some surgeons believed that, if open operation was

indicated, there would be less likelihood of synostosis from excessive calcification if two incisions were used.

TRAINING INJURIES

Fractures of the bones of the forearm were frequent at all training camps (p. 227) and presented the problems that such fractures do in civilian life. Closed reduction was satisfactory in many cases, but in many others, open reduction was necessary to obtain satisfactory position and a good anatomic and functional end result.

In some of the fractures of the forearm transferred to the Station Hospital at Camp Maxey, Tex., for further treatment, immediate improvement was effected by the simple expedient of modifying the amount of pronation-supination in which the forearm was immobilized.

When both bones were fractured, open reduction and internal fixation were carried out at once, usually with good results. Bone grafts for nonunion were not often required.

Case 1.—A patient with radial-ulnar synostosis treated at the hospital at Camp Maxey had sustained a fracture-dislocation of the elbow, with comminution of the radial head. The damaged head had been removed and the dislocation reduced without difficulty. Although subsequent roentgenograms showed no proliferation from the radial stump proximally or about the elbow, a solid 1-inch synostosis occurred between the bones, completely abolishing pronation and supination. About 80-percent function was restored by approaching the synostosis through a Boyd posterior incision, removing the synostosis, and interposing between the bones a large flap from the extensor carpi ulnaris, which was brought up from below on the medial aspect of the ulna.

FRACTURES OF THE LOWER END OF THE RADIUS

Fractures of the lower end of the radius are more common in older age groups than in younger, and their relatively low incidence in military personnel—about 5 percent of all fractures—was commented on at the 1943 Army Air Forces conferences (*1*).

Recommendations for their management at these conferences included:

1. The complete or nearly complete Cotton-Loder position of flexion and ulnar deviation after reduction. Some officers favored inclusion of the thumb in the cast, to provide for its more rigid fixation. Those who recommended the full position advised that it be changed to one of decreased volar flexion after 2 or 3 weeks. Only one officer maintained the full position for 6 weeks.
2. A position of slight flexion and ulnar deviation, on the ground that the full Cotton-Loder position introduced the risks of stiffness and of median nerve injury.
3. The neutral position.
4. The traction technique of Joldersma, which requires the use of 15 pounds of traction on the hand, obtained through special finger splints, for 15 minutes at a time.
5. Wire traction through the base of the first metacarpal, or the bases of all the metacarpals, to maintain reduction in extensively comminuted fractures.

It is curious that only twice was it stated at these Army Air Forces conferences that, in the management of fractures of the lower end of the radius, the elbow should be immobilized, although this practice is routine in civilian life after reduction of a Colles' fracture.

Reduction was usually accomplished under general anesthesia, though brachial block was occasionally recommended, and six hospitals reported the use of local anesthesia. It was Colonel Shands' opinion that local anesthesia was almost never the method of choice in military surgery, and his opinion was substantiated by the fact that the only poor results reported at these conferences in fractures of the lower end of the radius were from hospitals in which local anesthesia was used. One officer, who strongly condemned its use, did so on the ground that when it was employed, the surgeon was inclined to stop short of complete reduction because of the patient's pain and discomfort; in his opinion, many poor results in fractures of the lower end of the radius could be explained by the use of insufficient force in their reduction.

Section II. Combat-Incurred Injuries

GENERAL CONSIDERATIONS

Combat-incurred injuries of the forearm were caused chiefly by shell fragments, hand grenades, and rifle fire. Landmines only occasionally were responsible. When these injuries were observed in hospitals in the Zone of Interior, no matter how well they had been treated overseas—where they were usually treated very well indeed—the fractures were associated frequently with severe bony fragmentation as well as loss of bone substance, further complicated by loss of skin, destruction of muscles and tendons, and nerve injuries. Moreover, several, and sometimes all, of these complications frequently were present in the same patient.

While the procedures in each case depended upon the needs in that special case, the surgery of combat-incurred fractures of the forearm in Zone of Interior hospitals included the following techniques (*2*):

1. Skin defects had to be closed after osteomyelitis and other deep infections had been controlled. Good results, which were often spectacularly good, were achieved by excision of scar tissue, undermining, and wound closure; split-thickness skin grafts; and pedicle grafts.

2. Combined nerve-bone injuries were handled by combined orthopedic surgery and neurosurgery, frequently performed at the same operation. If this was not practical, the preferred order was nerve, and then orthopedic, surgery. These matters are discussed at length in the volumes dealing with neurosurgery in this historical series (*3*, *4*).

3. Surgery was undertaken only after there was complete confidence that the overlying skin and the underlying tissue were healthy and that there had not been the slightest serous or purulent discharge from the damaged area for a certain period,

usually a minimum of 3 months. These criteria were imperative. Without them, the incidence of postoperative infection could have been intolerable.

4. When open reduction was necessary, both bones could occasionally be operated on through the same incision, but good accessibility usually required two incisions.

5. Internal fixation by plates and screws was required in most cases to hold bones in position if they could be brought into direct contact after angulation had been corrected and the ends freshened.

6. If bony defects of any substantial size existed after reduction had been accomplished, bone grafting was generally necessary. The type of graft used and the technique employed depended upon the fixation required, the amount of bone loss, and the surgeon's judgment and experience.

TECHNICAL CONSIDERATIONS

In the reconstructive surgery of the forearm at Ashford General Hospital, White Sulphur Springs, W. Va. (*5*), it was always borne in mind that the ability of the radius to rotate on the ulna greatly enhances the economic and other usefulness of the hand and is often more important than humeroulnar motion. This ability could be interfered with at any point along the course of these bones by scarring, synostosis, malunion in faulty alinement or rotation, or soft-tissue scarring from extensive fibrosis. Pathologic processes in the upper third of the radius and ulna were particularly difficult to handle in the attempt to restore supination and pronation.

The best incision for most surgery on the shaft of the radius was the Henry approach, along the medial border of the brachioradialis. At Ashford General Hospital, this incision was modified into a double-curved skin incision, as a precaution against the development of keloids and restriction of joint motion. Visualization by this incision was excellent, and any risk of damage to the dorsal interosseous nerve was avoided.

Observation of the insertion of the biceps tendon into the radial tuberosity afforded a reliable guide to the proper rotation of bone fragments. If necessary for the exposure of the radio-ulnar structures proximal to it and hidden by it, the insertion could be severed. It was easily reinserted by use of the Bunnell wire pullout technique (*6*).

Bridging of gaps in the forearm was accomplished by full-thickness bone grafts, with adequate fixation and an appropriate vascular bed. In several instances at Ashford General Hospital, radial gaps were bridged successfully when the vascular bed was located in the head of the radius.

At times, destruction of the bones of the forearm was so devastating that the temptation was strong to make a one-bone forearm. It was always resisted. Such a procedure would mean complete loss of supination and pronation. As long as the head of the radius was present and viable, an attempt to restore the bones by grafts was justified. If necessary, the distal end of the graft could be impaled into the carpus. If basic principles were otherwise met, there was reasonable hope for vitality of the graft.

Excision of the distal end of the ulna was regarded as a most reliable

operation. The indication for it was any disabling pathologic process of the distal radio-ulnar joint or of the distal ulna. The operation relieved, or improved, limitation of dorsiflexion, palmar flexion, supination, and pronation, as well as pain on any of these movements. It was also useful in painful recurrent dislocations of the radio-ulnar joint. Only when the process was in the ulna itself was that bone shortened more than to a point just proximal to its articulation with the radius.

Resection of the distal end of the ulna was employed to gain alinement of a short distal radial fragment fixed in malposition. Frequently, even when such a fragment was stripped completely of periosteum, its proximal end persisted in deviating toward the radius. Correction was achieved by appropriate subperiosteal resection of the distal ulna. The alternative was restoration of the radial length by preoperative traction.

POSTOPERATIVE MANAGEMENT AND REHABILITATION

Postoperative immobilization of all fractures of the radius and ulna was always in plaster, maintained long enough to assure solid bony union. The necessary period varied from 10 weeks to 4 months. Too early removal of the cast could result in angulation, and, if internal fixation or bone grafting had been used, in loosening of the screws or fracture of the graft. Immobilization for too long a period militated against return of function, particularly in cases in which scar tissue was a problem. Directives stressed that no cast should extend beyond the knuckles posteriorly or the midpalmar crease anteriorly.

Elevation of the extremity after injury and operation reduced pain, prevented edema, and also prevented the development of fibrosis.

Active motion of joints not mobilized was begun immediately after operation, and physical therapy was used according to the indications of the special case. At Ashford General Hospital, great stress was laid upon the earliest possible use of occupational therapy, in the form of interesting, purposeful, useful work, of graded difficulty, and within the range of the patient's ability and skill. When it was at all practical, the work was put on a remunerative, piecework basis as soon as possible.

A great deal of apparatus was devised during the war for use in the rehabilitation of patients with injuries of the extremities.

REPAIR OF RADIAL DEFECTS BY GRAFTS FROM THE FIBULA

A report by Capt. Richard C. Miller, MC, and Maj. George S. Phalen, MC, from O'Reilly General Hospital, Springfield, Mo., concerned 16 fractures of the radius repaired by grafts from the fibula over an 18-month period (7). Previously, grafts from the fibula had been used only occasion-

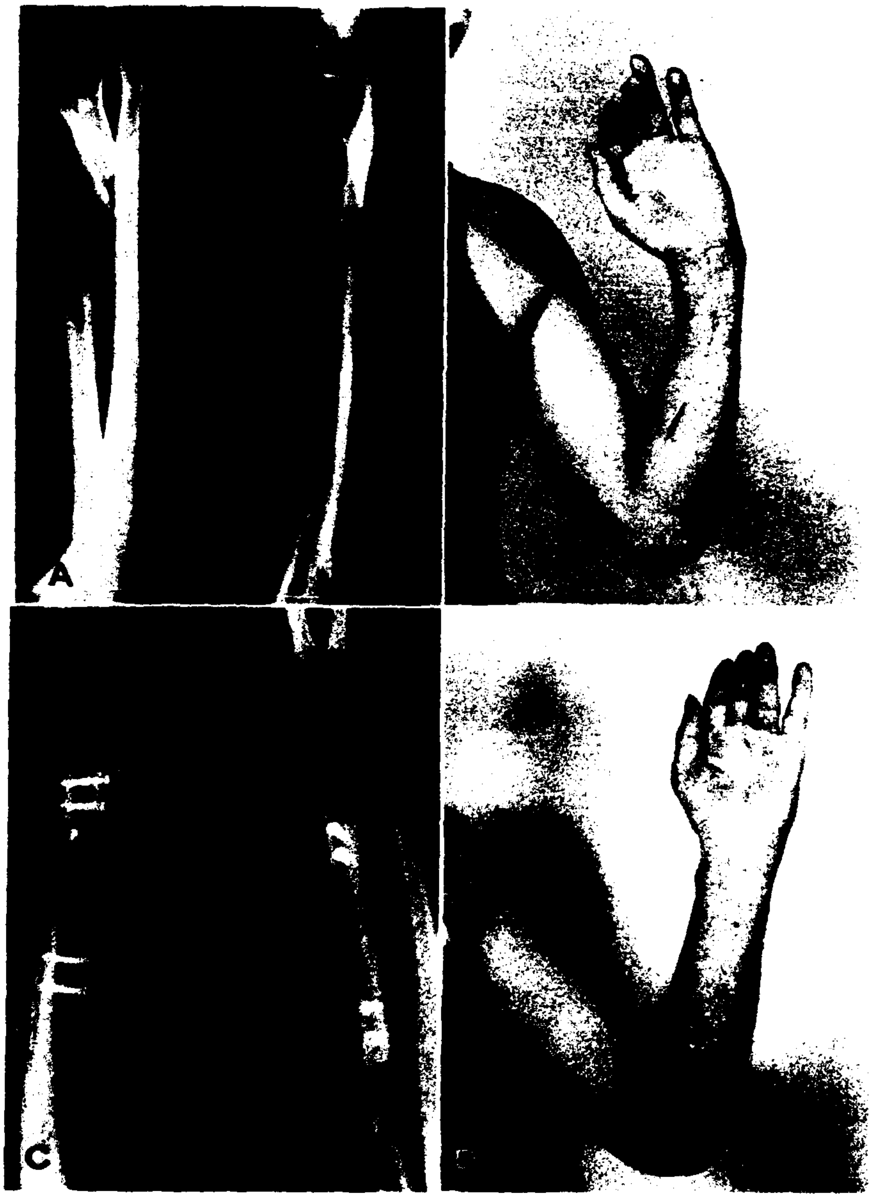

FIGURE 144.—Management of combat-incurred defect of radial shaft by fibular graft. A. Anteroposterior and lateral roentgenograms of left forearm 6 months after shell wound. Note defect in radial shaft, angulation of distal radial fragment, relative increase in length of ulna, prominent ulnar styloid process, and several retained metallic foreign bodies. B. Preoperative photograph of left arm, showing healed wound, radial deviation of hand, and prominence of ulnar styloid process. C. Lateral and anteroposterior roentgenograms 3 months after insertion of fibular graft and resection of distal portion of ulna. Radial length has been restored. The fibular bone graft, fixed by two screws above and two screws below, has incorporated with the radial shaft. Several metallic foreign bodies are still apparent. D. Photograph of left arm showing normal contour of forearm and no prominence of ulnar styloid process. At this time, the fracture was united and pronation and supination were rated good.

ally for any bones except the tibia and femur. The fibula, however, has the advantage of being the same size as the radius, which meant ultimately normal contour of the radius, and presumably, normal strength. It provided considerable stability to the injured bone, and when it was used, the risk of fracture of the donor bone, always present when the tibia was used, was avoided. On the other hand, the fibula, as compared with tibial or iliac grafts, has a relatively greater amount of dense cortical bone, and its osteogenic properties are correspondingly reduced.

Indications.—Typically, the fractures of the radius for which this technique was employed (figs. 144 and 145) were the result of perforating wounds of the forearm by high velocity missiles, with resulting destruction of a portion of the radial shaft, and with no bridge, or an entirely inadequate bridge, of bone between the major fragments to encourage healing. In the 16 fractures in this series, either the ulna had escaped damage or it had sustained a fracture which had already healed. In many instances, there was associated loss of muscles and skin and, very often, nerve damage.

The injuries in this series had certain characteristics:

1. Prominence of the distal end of the ulna and marked radial deviation of the hand because of the relative overlength of the ulna, which resulted from shortening of the radius.
2. Loss of active pronation and supination, which resulted when the loss of bone in the radial shaft was distal to the insertion of the pronator teres. In such cases, the proximal radial fragment could be felt to pronate and supinate satisfactorily, but the hand could not rotate because of the loss of bony continuity in the radius. The strong rotators (the biceps brachii, supinator, and pronator teres) could no longer act on the distal radial fragment, and the weak rotators (the brachioradialis and the pronator quadratus) either had been damaged by the original injury or were not strong enough to accomplish any appreciable rotation of the wrist and hand.
3. Frequent loss of extension power in the fingers and thumb, variously due to severance of the deep branch of the radial nerve or actual avulsion of muscular substance.

Preoperative management.—Before the bone graft was attempted, any necessary surgery on the skin was done. It might range from simple excision of scar tissue to a major plastic procedure. If the scar was narrow and the skin edges could be approximated without tension after it had been excised, the bone graft could be applied at the same operation, but this technique was not recommended. Once the graft was in place, the normal or almost normal contour of the arm would be restored, and no chance could be taken that the circumference would be lessened by previous excision of scar tissue, for fear of placing too much tension on the skin edges when the bone graft was inserted. A tubed pedicle graft or abdominal flap graft was employed in the seven cases in this series in which simple excision of scar tissue seemed unlikely to provide an adequate soft-tissue covering. The bone graft was not inserted for 6 to 8 weeks after the pedicle graft. Care had to be taken, when a pedicle graft was used, not to undermine more than

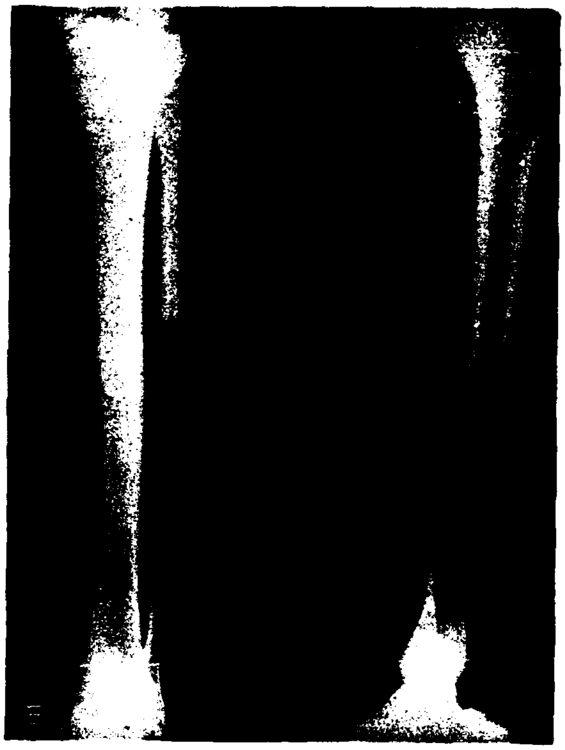

FIGURE 144.—Continued. E. Anteroposterior and lateral roentgenograms of tibia and fibula 3 months after removal of fibular graft. There is minimal regeneration of the fibula at the donor site. The soldier had no complaints referable to his leg at this time.

50 percent of its width because of the risk of impairing the circulation to the edge of the graft.

Also important before bone grafting were curettage of sinuses, sequestrectomy, and removal of foreign bodies, to permit complete wound healing and to prevent postoperative infection. If only scar excision had been necessary and no complications had appeared, an 8-week waiting period was generally satisfactory. Even in uncomplicated cases, however, bone grafting was not carried out for at least 12 weeks after healing, while when healing was delayed for any reason, a delay of 6 months or more was the rule.

Provision of fibular graft.—The fibular graft was obtained from a normal leg, preferably the leg opposite the involved arm, to give the second surgical team more room to work. The fibular shaft was exposed subperiosteally through a lateral longitudinal incision. Dissection was carried down along the posterior intermuscular septum between the peroneal and soleus musculature, care being taken not to traumatize these muscles. The graft was removed with a Gigli's saw or osteotome. Proximally, as much of the

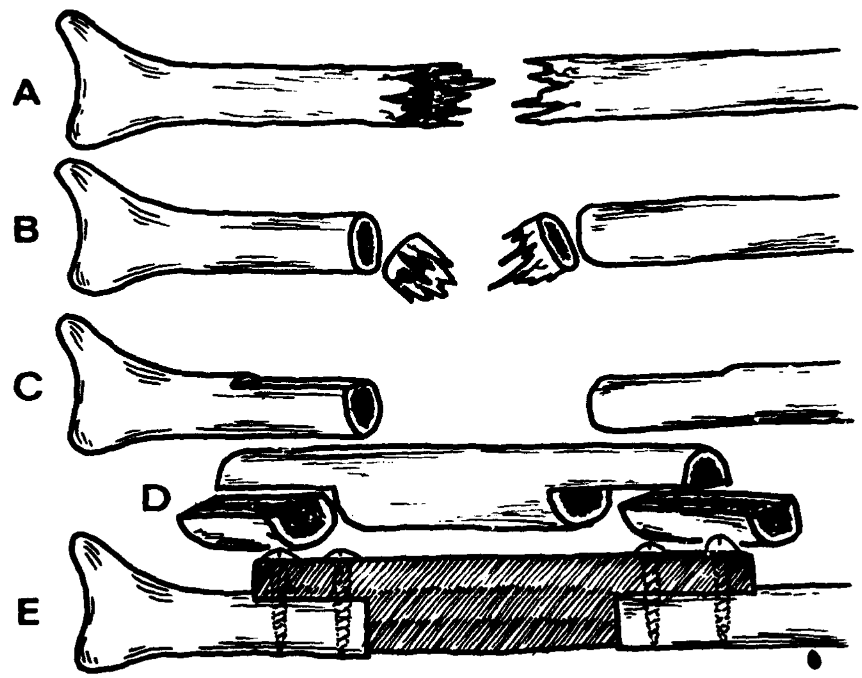

FIGURE 145.—Diagram showing procedure for insertion of fibular graft into defect of shaft of radius. A. Subperiosteal exposure of radial fragments. B. Squaring of bone ends, with removal of sclerotic bone. C. Preparation of fragments for reception of graft. D. Fibular graft cut to fit radial defect. E. Fibular graft (shaded area) fixed to radial fragments with Vitallium screws. (Miller, R. C., and Phalen, G. S.: J. Bone & Joint Surg. 29: 629–636, July 1947.)

fibula as was desired could be removed, including, if necessary, the head. The peroneal nerve, of course, was spared, particularly the deep branch as it rounded the neck of the fibula. Distally, at least 3 inches of the fibula was left in situ, to maintain the stability of the ankle mortise.

Technique.—In the arm, the distal end of the ulna was excised subperiosteally through a longitudinal incision 1½ inches long. In a few cases, at the same time, a slip of palmaris longus tendon was excised and used to encircle the ulna and anchor it down to the flexor carpi ulnaris muscle, to overcome the tendency for the ulna to dislocate when the arm was rotated. The value of this step was considered questionable.

An adequate longitudinal incision was next made over the fractured area of the radius, the exact site being determined by the location of the fracture and by scarring of the skin. A dorsolateral incision was considered best. The superficial branch of the radial nerve was immediately identified and was protected throughout the operation. Dissection was carried down through the muscular planes, usually between the extensor carpi radialis longus and the brachioradialis. The radial fragments were exposed subperiosteally for at least 1½ inches. Scar tissue and devitalized bone fragments were removed from the site of nonunion. The ends of both radial fragments were sawed

back at right angles to the shaft until the sclerotic portions had been removed and healthy vascular bone was apparent.

The radial defects, measured after surgical squaring of the bone ends, which usually required resecting from one-fourth to one-half of an inch in both fragments, ranged from 1 to 5½ inches. The grafts were generally cut 3 inches longer than the defect, to allow for a 1½ inch onlay on each fragment. In two cases, the defect was so close to the wrist joint that the distal onlayed portion of the graft had to be shortened to 1 inch.

Half the thickness of the fibular graft was sawn from each end. This left the central portion of the graft the full thickness of the fibular shaft and measuring exactly the same length as the bony defect to be bridged. Care was taken not to extend the saw cuts more than half way across the fibular shaft, to avoid the risk that it might fracture in this area.

After the radial fragments were alined, a decision was made as to which surface—lateral or posterior—of the radius the graft would be applied to. The selected surfaces of the radial fragments were leveled with an osteotome, so that precise contact could be obtained between the graft and each of the fragments. If the length of the radial defect was measured while traction was applied to the hand, the fibular graft could be mortised in snugly between the fragments. When traction on the hand was released, the end of each radial fragment would come up tightly against half of the fibular shaft, and the half-thickness fibular ends would lie in close contact with the freshened area on each radial fragment as onlay grafts of about 1½ inches.

The fibular graft was usually fixed in place with two Vitallium screws in each fragment, though in some instances, a single screw and a loop of tantalum wire were used, to avoid weakening the graft by a second screw hole. If the distal radial fragment was so osteoporotic that screws would not hold, two double strands of No. 22 tantalum wire were used. The wound was closed in layers.

The distal end of the ulna was resected in 11 cases. In the first operation in the series, it was found that, even after the distal radial fragment had been completely exposed subperiosteally, it was still not possible to correct its marked deviation. After the distal end of the ulna had been resected, however, the distal radial fragment was freely movable and could be readily alined with the proximal fragment. In most subsequent operations, therefore, the first step was resection of the ulna, to eliminate possible future difficulties with radial deviation of the hand.

Postoperative management.—The long arm plaster cast applied after operation, with the elbow at a right angle and the forearm in neutral position, was heavily padded, to allow for swelling. Suspension straps were incorporated in it, to keep the arm elevated for 48 hours. The patient was then told that he might lower it whenever he wished, but the elevated position was usually found so comfortable that advantage was not taken of the permission until the third or fourth day.

The cast was removed, the wound inspected, and the sutures removed any time after the 18th day. By this time, the cast had become rather loose. It was replaced by another, snug-fitting cast, with minimal padding, and with the hand portion trimmed back enough to permit full motion in the fingers and thumb.

The cast was worn for at least 6 months; it was usually changed, and serial roentgenograms were taken, at 6-week intervals. After it was re-

moved permanently, a metal and leather brace was used for another 2 or 3 months. It was imperative that the graft be protected against all risk of fracture till there was clear-cut roentgenologic evidence that it was well incorporated into the radius.

Physical therapy was instituted to mobilize the elbow and wrist as soon as the plaster cast was permanently removed. Forceful active and passive rotation of the forearm was not permitted, however, until there was roentgenologic evidence of complete healing.

Ambulation was permitted as soon as the leg wound healed, usually about the 10th day. No special instructions were given about walking; the patients simply were reassured and told that they might be up and about as soon as ambulation was comfortable. At first, they were somewhat hesitant and inclined to use some support. This was discarded within 2 or 3 weeks. Within a month of operation, they walked normally, without any limp, and they had no complaints referable to the donor site. In none of the 16 cases was there any evidence of disability. It was exceptional for any patient, even when questioned specifically, to state that the donor leg did not feel as strong as before operation.

Results.—Recovery was smooth in every case in the series except one, in which, in spite of all the precautions taken, purulent drainage appeared 12 weeks after operation. Sequestration followed, and while eventual bony union was achieved by involucrum, rotation was extremely restricted.

Fracture of the fibular graft did not occur in this series but was observed in two fibular grafts of the ulna, in both of which trauma was minimal. Both of these fractures occurred at the junction of the graft and the ulnar fragment, which suggested the need for extremely accurate contact between the fibular graft and the radial fragments, so that healing would occur not only between the onlayed portion of the graft and the fragments but also between the fragments and the portion of the graft that had been mortised in between the ends of the fractured bone. Fibular grafts were probably more slowly revascularized than similar grafts from the tibia or ilium, and immobilization in some cases was, therefore, continued for 14 to 18 weeks, with protection by a metal and leather brace, with hinged elbow and palmar bar, for another 8 to 12 weeks. This precaution was observed in this series only when roentgenograms showed some delay in complete incorporation of the graft into the radius, but it should probably have been used universally. It permitted mobilization of the elbow joint but, at the same time, prevented rotation of the forearm and protected it until complete vascularization had occurred.

In three of the five cases in this series in which the distal end of the ulna was not resected, rotation of the forearm was greatly restricted. In two of these three cases, the total range of rotation was 30 degrees and in the third, the instance of infection just described, the range was 20 degrees. In the two other cases in which the ulna was not resected, the fractures had healed with sufficient shortening for the relative length of the two bones to

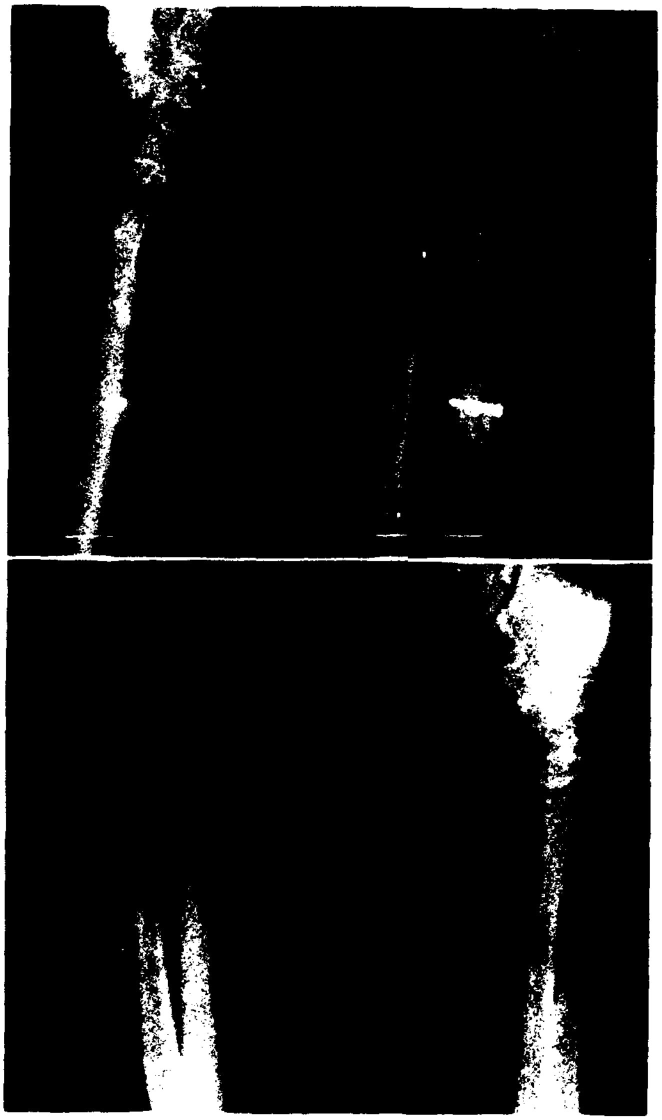

FIGURE 146.—Management of combat-incurred defect of lower radial shaft by tibial bone graft. (Top) Anteroposterior and lateral roentgenograms of right forearm showing defect in lower radial shaft with angulation of distal radial fragment and relative lengthening of ulna, with prominent distal end (29 January 1945). (Bottom) Lateral and anteroposterior roentgenograms 4½ months (10 October 1945) after dual tibial bone grafts were applied across the radial defect. The fracture is healed. The relative increase in length of the ulna and the prominence of the ulnar styloid process persist. If these conditions should cause symptoms, the probable procedure would be resection of the distal portion of the ulna. No further record of the case is available.

be restored without additional resection of the ulna.

All but one of the 11 patients in whom resection of the distal ulna had been carried out regained a satisfactory range of rotation of the forearm (more than 100 degrees). The remaining patient had an active range of rotation of 20 degrees and a passive range of 50 degrees. At the time the report was made, he was still wearing a brace which prevented rotation of the forearm. This man, who had the largest defect in the series, had apparently lost the action of the strong rotator muscles.

ANALYSIS OF CASES

The 275 fractures of the radius, the ulna, or both bones treated at Harmon General Hospital, Longview, Tex., occurred in a total of about 3,000 fractures in all areas (*8*). Practically all of the injuries were received from overseas, and it was exceptional for patients to arrive in anything but excellent condition.

More than 80 percent of these fractures were treated by closed plaster techniques, with satisfactory results. The following methods were used in the other cases:

1. Resection of the head of the radius was carried out in some cases because of deformity of the elbow joint or limitation of function.
2. In a few cases, the proximal tip of the olecranon was resected and the triceps tendon repaired by suturing it into the distal lower surface of the olecranon. Results were excellent if the fractured fragment of the olecranon did not constitute more than 1 inch of its proximal portion.
3. Good functional results were obtained by resection of the distal portion of the ulna in radial fractures which had healed with some shortening and in which the distal ulnar styloid process was prominent.
4. Severe fractures involving the wrist joint, in which satisfactory function could not be obtained, were treated by arthrodesis of the radiocarpal and the second, third, and fourth carpal-metacarpal joints. Every patient in this group eventually had a strong, useful forearm.
5. Draining sinuses associated with wound infections and osteomyelitis complicating internal fixation operations were treated by excision of the sinuses and removal of all foreign material. In a number of badly infected fractures, substitution of full-thickness skin grafts for the split-thickness grafts originally applied resulted in union.
6. Bone grafting was generally successful (fig. 146) even before penicillin became available, whether it was done for simple nonunion or for replacement of massive bone defects.

A summarized statistical breakdown of the 275 fractures in this series shows the following immediate results:

- Ninety simple fractures, including—
  - Thirty-two fractures of the radius, with 29 good results.
  - Twenty-one fractures of the ulna, all with good results.
  - Thirty-seven fractures of both bones, with 32 good results.
- One hundred eighty-five compound fractures, including—
  - Sixty-five fractures of the radius, all with good results.

Sixty-eight fractures of the ulna, with 66 good results.

Fifty-two fractures of both bones, with 40 good results and four fair results.

The eight failures in the 90 simple fractures all followed internal fixation, as did five of the seven failures in the 185 compound fractures. In the simple fractures, 68 of the 82 good results were achieved by closed reduction, as were 155 of the 171 good results in the compound fracture group. There were, in fact, only two failures in the whole series when this technique was used, both in fractures of the ulna. The statistics need no comment.

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CHAPTER XX

Fractures of the Carpal Scaphoid Bone

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

GENERAL CONSIDERATIONS

At a meeting of the Subcommittee on Orthopedic Surgery, Committee on Surgery, National Research Council, on 2 June 1942 (*1*), when the United States had still had little wartime experience, Col. J. A. MacFarlane, RCAMC, Chief Medical Consultant, Canadian Armed Forces, discussed a number of injuries sustained by the British Armed Forces. What he said then concerning fractures of the carpal scaphoid might well be used as the summarized experience of the U.S. Armed Forces with this apparently minor injury.

There were many such fractures, he said. It was necessary to diagnose them promptly and treat them vigorously, by fixation, if good results were to be achieved. Three months' immobilization in skintight plaster was the minimum for success. Results with late diagnosis and delayed treatment were bad, no matter what method was used. If arthritic changes had occurred in fractures seen late, no surgery was useful. Grafts usually failed. The best plan was to "rate" the patient and return him to any duty for which he was fitted, industrial or otherwise. He could not be a combat soldier again.

Carpal scaphoid fractures are frequent in civilian life and it is not surprising that in the Army, just as in civilian life, they were so frequently overlooked until the optimum time for treatment had been allowed to pass. In civilian life, an error of this kind might mean an economic disaster for the patient. In the Army, in which physical demands of both training and combat are exacting, it frequently meant an intolerable loss of manpower and, in far too many instances, eventual separation from service.

The loss that these fractures represented in manpower is evident in every collected series. One citation is sufficient: In 45 cases reported by Maj. (later Lt. Col.) Benjamin E. Obletz, MC, from the 23d General Hospital (*2*), the average time required for healing in 37 fractures without interruption of the blood supply was 8.3 weeks. In the remaining eight cases, in which the blood supply was interrupted, healing took 19 weeks. Disappearance of the fracture line was the criterion of healing. These figures mean that, in this small series, there was a total manpower loss of

307.1 weeks for the first group and of 152 weeks for the second, which is a combined total of 8.8 work years. Other series, both in the Zone of Interior and overseas, represented the same heavy losses.

These losses, even when the injuries were treated correctly, are the justification for utilizing so much space in this volume for an apparently trivial injury. Actually, it was an injury that was anything but trivial in its consequences.

This whole presentation, it should be noted, falls into two divisions, (1) carpal scaphoid fractures diagnosed promptly and treated correctly, and (2) fractures which were overlooked or badly treated and in which nonunion was present.

INCIDENCE

The earliest reports from training camps in the Zone of Interior made it clear that fractures of the carpal scaphoid would be a frequent injury. In the larger training camps, with their emphasis on obstacle courses and on major sports, these fractures were an almost daily occurrence. The Consultant in Orthopedic Surgery, the Surgeon General's Office, once noted in his official diary that at Gorgas General Hospital, Panama, C.Z., three such fractures had occurred in a 3-day period. Maj. Moss M. Bannerman, MC, reported that the 66 fractures he observed at Harmon General Hospital, Longview, Tex., and LaGarde General Hospital, New Orleans, La., represented 5 percent of the total number of fractures observed at these hospitals over a 2-year period (*3*).

The Army Air Forces figures bear out the Army figures. At the conferences held in October 1943 (*4*), one hospital reported 91 carpal scaphoid fractures in 110 fractures of the wrist. Another reported 47 in 280 fractures of the hand and wrist. Six other hospitals variously reported 9, 12, 16, 23, 47, and 91, a total of 198. In civilian life, according to Key and Conwell, the incidence of such fractures is 0.5 percent (*5*).

Early in the war, many carpal scaphoid fractures were lost under the diagnosis of sprained wrists. When roentgenographic examination became routine in such injuries, almost all of these fractures were recognized, and the strict diagnostic routine is one explanation of the very large number observed.

The statistical and other data in this chapter are derived chiefly from the following reports, in addition to the 45 (fresh) fractures reported by Major Obletz in 1944 (*2*) and the 66 fractures reported by Major Bannerman in 1946 (*3*) and already mentioned:

Sixty-three (un-united) fractures reported by Maj. James V. Luck, MC, and his associates from AAF (Army Air Forces) regional hospitals (*6*). Many of the patients had reached these hospitals from small station hospitals which had no orthopedic surgeons. Simple carpal scaphoid frac-

tures were treated in station hospitals, but patients with nonunion or avascular necrosis were transferred to regional hospitals.

Fifty fractures reported by Dr. (later Lt. Col., MC) Ralph Soto-Hall and Dr. Keene O. Haldeman, from their prewar civilian practice (*7*). All their remarks, however, are militarily applicable.

Twenty-three (un-united) fractures reported by Maj. Joseph E. Milgram, MC, from Schick General Hospital, Clinton, Iowa (*8*).

Most of these fractures occurred in young men. In the Army Air Forces series, which is typical, the age range was from 20 to 44 years and the average age was 26 years. In this same series, 44 of the 63 injuries were line-of-duty-yes.

ANATOMIC CONSIDERATIONS

The anatomic peculiarities of the carpal scaphoid had a direct bearing on both the occurrence of fractures in it and their healing.

The scaphoid is the largest bone in the proximal row of bones of the wrist. It is elongated and is somewhat constricted at the mid portion (waist), at which most fractures occur. When it is freed of its soft-tissue attachments, it appears to be almost entirely smooth. Most of its surface consists of articular cartilage, which articulates with five bones; namely, the radius, the lunate, the greater and lesser multangular bones, and the capitate bone.

A narrow ridge, running obliquely around the dorsal surface of the scaphoid, from the tubercle on the lateral side to the proximal base medially, contains the arterial foramina through which the scaphoid receives its blood supply. In 1938, after an examination of 297 bones, Obletz and Halbstein reported a considerable variation in the distribution of these nutritive foramina (*9*). In 67 percent of the bones examined, both the proximal and the distal portions were adequately supplied with them, and every specimen had at least a few in the tubercle and the distal portion of the bone. But in 13 percent of the bones, there were no foramina proximal to the waist. These observers, therefore, concluded that a fracture through the waist of the bone could interrupt the blood supply to the proximal fragment in between 13 and 33 percent of all injuries.[1]

If the situation was recognized, and immobilization was carried out properly or surgery was resorted to, it was concluded further that the avascularity described would be only transient and revascularization would occur, though healing might be somewhat delayed. If the diagnosis was overlooked and the wrist was not adequately immobilized, shearing movements at the fracture site would prevent the growth of new vascular channels to the proximal fragment and it would slowly die. This subject is discussed more fully under roentgenologic examination of these fractures (p. 581).

On the basis of the anatomic variations in the blood supply, the effect

[1] The theory is ingenious, but the experience of the Army Air Forces pointed to delay in diagnosis and errors of immobilization as responsible for far more cases of nonunion than an impairment of the blood supply, absence of periosteal callus, and bathing of the fracture site in synovial fluid.—A. R. S., Jr.

of these variations on fracture healing, and serial roentgenologic studies, Major Obletz divided his 45 fractures into two groups (*2*):

Thirty-seven fractures without interruption of the blood supply to either fragment. It would be expected that the majority of the fractures would fall into this group, since two-thirds of all scaphoid bones have an adequate distribution of arterial foramina throughout their long axes.

Eight fractures with interruption of the blood supply to the proximal fragment.

LOCATION

Fractures of the carpal scaphoid were observed in World War II in the following locations:

1. In the tubercle, at the attachment of the transverse carpal ligament. These fractures, all of the avulsion type, were infrequent and healed rapidly and uneventfully.
2. In the tubercle, extra-articularly. These fractures, also infrequent, were extra-articular and were also capable of quick healing because the bone in this area is well covered by periosteum and well vascularized.
3. At the waist. Fractures in this area were more frequent than in any other area and more serious. Major Obletz' report of 35 fractures in this location in 45 injuries is typical (*2*). Healing depended upon the status of the blood supply to the proximal fragment. If it was adequate, healing occurred after 8 to 10 weeks of immobilization. If it was not, healing might require 20 weeks or more. There was no way of determining in advance into which of these two groups a fracture would fall.
4. In the body. Fractures in this area, which were common, might be linear or might show some displacement or angulation.
5. At the proximal pole. Fractures involving the small part of the proximal bone had a very poor blood supply and a very unfavorable prognosis.

MECHANISM

The mechanism of carpal scaphoid fractures was practically always the same, which was an important diagnostic consideration:

The soldier fell, or was thrown to the ground, and, in an automatic attempt to break the fall, he landed on his outstretched hands, usually on the palmar surfaces. The wrist was in dorsiflexion and rigidly fixed by the strong muscles of the forearm. The heel of the palm, which struck the ground first, took the shock of impact, the force of which was transmitted to the scaphoid along the radial axis of the hand and forearm, and the bone cracked at its weakest point mechanically; that is, the waist (*10*).

In support of this explanation of the mechanism of scaphoid fractures

is the high incidence of hairline fracture shadows and more distinct fracture lines through the waist, without any anatomic displacement of the fragments, though it might seem that any element of hyperextension of the wrist would separate the fragments after fracture. In 42 of the 45 carpal scaphoid fractures reported from the 23d General Hospital (*2*), there was absolutely no displacement of the fragments. When displacement was present, however, it could usually be corrected only by open reduction. If it was not corrected, nonunion was almost inevitable.

The mechanism just described also explains the far greater incidence of carpal scaphoid fractures than of Colles' fractures in the Army, which was the reverse of the situation in civilian life (*10*). During the 18 months in which 45 carpal scaphoid fractures were observed at the 23d General Hospital, only 10 Colles' fractures were observed (*2*). Approximately the same discrepancy was observed at Fort Jackson, S.C. (*10*). The explanation was that the strong muscles of young, vigorous soldiers resisted indirect violence and their wrists did not hyperextend as they fell, though the scaphoid might fracture. In older persons, particularly women and sedentary workers, with flabbier muscles, the wrist hyperextends and a Colles' fracture is the result.

Associated injuries were not frequent. There were only two in the 45 fractures at the 23d General Hospital (*2*). One was a transverse crack fracture 1 inch from the distal end of the radius, without displacement. The other was a Bennett fracture-dislocation of the base of the first metacarpal bone.

Fractures of the scaphoid were associated with dislocations of the lunate bone in about 12 percent of all cases (*11*). The dislocation was explained by the same mechanism that had produced the scaphoid fracture; that is, dorsiflexion of the wrist in a fall. If the lunate bone was involved in the original injury, it usually remained in situ and the rest of the carpus dislocated around it dorsally.

Some dislocations of the lunate bone were caused therapeutically. The wrist was necessarily held in slight volar flexion for the first 4 weeks after injury; if it was placed in dorsiflexion, dislocation of the lunate bone was a possibility.

DIAGNOSIS

Even for medical officers with a low index of suspicion, carpal scaphoid fractures should have been easy to diagnose. The story, as just pointed out, was practically always typical. After a fall on the outstretched hand or some similar trauma, the patient complained of pain at the radial aspect of the carpus and of inability to grasp anything firmly. Because of pain, both active and passive motions were restricted.

Examination immediately after injury showed constant tenderness between the long and short extensors of the thumb or over the anatomic

snuffbox. A clinical diagnosis of fracture of the carpal scaphoid, even without evident deformity and before roentgenographic evidence was adduced, was fully justified by these findings. A diagnosis of sprained wrist was not. In fact, it was sound surgical teaching that in military surgery as well as in civilian life, a sprained wrist did not exist until a fracture of the scaphoid had been positively excluded clinically and roentgenologically.

One or two refinements of diagnosis were useful. At the 1943 AAF conferences (*4*), one medical officer reported that tapping on the fingertips would cause pain in the wrist in a large proportion of fractured scaphoids. In their 1941 report, Soto-Hall and Haldeman had pointed out that pain could be produced over the scaphoid area by percussion on the tip of the abducted thumb or over the distal end of the second metacarpal (*7*). Forced ulnar flexion of the wrist also caused pain, as did movement of the distal phalanx of the thumb because of the mobility it caused at the fracture site.

Ideally, carpal scaphoid fractures should have been diagnosed without delay. Early in the war, a great many of them were not. Later, the situation was improved, but at best, there were frequent delays. In the 66 fractures reported from Harmon and LaGarde General Hospitals (*3*), diagnosis was delayed beyond 30 days in 28 cases and beyond 180 days in 12 (table 9). In five instances, the men did not report the accident until several weeks after it had occurred, but in the remainder of delayed cases, the diagnosis was simply missed. The condition was classified as a sprain, or roentgenographic examination was omitted, or a negative roentgenographic diagnosis was accepted. Even if the roentgenograms were negative, the clinical findings in these cases would have warranted a tentative diagnosis of scaphoid fracture and trial immobilization. There is an instructive correlation in this series between delayed diagnosis and end results: Nonunion occurred only in the cases in which there had been a delay of 180 days or more, and it occurred in 10 of the 12 cases in this group in spite of immobilization on an average of 7½ months after the diagnosis had finally been made.

TABLE 9.—*Essential data in 66 fractures of the carpal scaphoid bone, Harmon and LaGarde General Hospitals*

Timelag between injury and diagnosis		Postinjury roentgenograms			Immobilization in months	Number of ununited fractures
Day	No. of cases	Positive	Negative	Omitted		
1–30	38	36	2	0	3.7	0
30–60	5	0	2	3	4.3	0
60–120	5	0	1	4	5.1	0
120–180	6	....	2	4	5.5	0
Over 180	12	....	3	9	7.5	10
Total	66	36	10	20		10

Source: Bannerman, M. M.: Fractures of the Carpal Scaphoid Bone. An Analysis of Sixty-six Cases. Arch. Surg. 53: 164–168, August 1946.

In the 63 un-united carpal scaphoid fractures analyzed by Major Luck and his associates, the diagnosis was made within 4 months or less in 10 cases, within 6 months in seven, within 12 months in 12, and within 2 years in eight. It was made after that time in 25 cases, 40 percent of the entire series (*6*). In this series, as in most other experiences, diagnosis was made more promptly when the fractures were line of duty.

The figures cited are typical. The remedy would have been further clinical and roentgenologic examination in every case in which pain and swelling persisted, especially in the region of the anatomic snuffbox. Swelling and moderate limitation of motion were less frequent than persistent pain, especially after exertion, and weakness.

The differential diagnosis of carpal scaphoid fractures was seldom a problem once medical officers had learned to consider sprain of the wrist as the last possible diagnostic resort and not the first. It included, whenever a history of a fall was in question, the following radial axis injuries (listed in order of anatomic sequence, but not of frequency): (1) fracture of the first metacarpal bone, (2) fracture of the greater multangular bone, (3) fracture of the carpal scaphoid, (4) perilunate posterior dislocation of the carpus, (5) Colles' fracture, and (6) fracture of the head of the radius. These lesions might occur in combination as well as separately.

Roentgenologic Examination

Major Obletz' detailed studies of carpal scaphoid fractures by serial roentgenographic examinations (*9*) produced the following observations relevant to the vascularity or avascularity of the proximal fragments, which has already been discussed (p. 577):

1. In fractures in which the blood supply was not interrupted:

a. On the day of injury, there might be no evidence of fracture, or the fracture line might be visible only as a hairline fissure or as a more easily recognizable crack. If any displacement was present, it was barely perceptible. The scaphoid and adjacent bones showed normal density.

b. Within 3 or 4 weeks after injury, the fracture line was more distinct and there was mild to moderate diffuse, homogeneous decalcification of cancellous bones of the carpus, including, to an equal degree, both fragments of the scaphoid.

c. Within 6 or 8 weeks after injury there was partial, and sometimes complete, obliteration of the fracture line. Decalcification had ceased, and some recalcification had occurred, though the entire affected carpus was less dense than the intact contralateral carpus. The density of both portions of the scaphoid was now equal to that of adjacent bones.

d. About 4 weeks later, if the fracture line had disappeared in earlier roentgenograms and the cast had been removed, normal density would be present in all the bones of the wrist, including the healed scaphoid.

2. In fractures in which the blood supply had been interrupted:

a. On the day of injury, the findings were identical with those in the first group, in which the blood supply was intact.

b. On the next examination, 3 to 4 weeks after injury, the fracture line was more distinct, as the result of reabsorption of calcium at this site. Generalized decalcification was present in all the bones except the proximal fragment of the scaphoid, which showed the same density as in the previous roentgenogram. Clearly, its blood supply had been interrupted and it was thus excluded from the reactive hyperemic decalcification going on in the other bones. Unless the degree of calcification was sufficient for contrast, the difference in density between the proximal and distal fragment might not be evident at this time.

c. At 6 to 8 weeks after injury, generalized osteoporosis of the carpus was usually more pronounced than in the first group of fractures. There was no difficulty, however, in recognizing the differences in density between the proximal fragment and the surrounding bones. The fragment had maintained its original calcium content and, therefore, its original density, and it stood out in sharp contrast to the osteoporotic surrounding bones. The fracture line was still visible.

d. At 10 to 12 weeks, the fracture line was beginning to disappear, but there was still a notable difference in density between the proximal fragment and the neighboring bone. There was sometimes evidence of beginning restoration of calcium to the carpus.

e. At 16 to 20 weeks, the fracture line was obliterated by the healing process. The difference in density between the fragments of the scaphoid was less marked; in fact, their densities now seemed to blend. If the cast was removed at this time, there was a return of normal density to the carpus within a few weeks. Subsequent examinations revealed no degenerative changes in the scaphoid, and at no time was there evidence of so-called creeping substitution in the proximal fragment (*12*).

Positioning

Roentgenographic examinations were usually made routinely in three positions: anteroposterior, lateral, and oblique. The oblique examination was made with the hand in the 45-degree position. The degree of ulnar deviation varied from moderate to marked. It was the experience at the 23d General Hospital (*2*), the hospital at Fort Jackson (*10*), and other hospitals that, when routine examinations were supplemented by projections in ulnar deviation and the 45-degree oblique position, even hairline fractures were seldom missed.

At LaGarde and Harmon General Hospitals (*3*), routine examinations were supplemented by semilateral views at angles of 30 and 60 degrees. With this technique, only two of 66 fractures were overlooked on the first examination, and both were diagnosed at a second examination 3 weeks later.

Colonel Soto-Hall recommended (*11*):

1. Lateral views, with both wrists in the same position, to permit careful comparison of the injured and uninjured hands. This was best accomplished by putting the palms together with the fingers pointing forward (the praying position).
2. At least two oblique views, with the palmar and dorsal surfaces of the wrist alternately against the film.
3. Posteroanterior films in complete ulnar deviation, to permit a view of the long axis of the scaphoid.

At one of the 1943 AAF conferences (*4*), attention was called to a

useful ring sign: Fractures of the carpal scaphoid, it was pointed out, usually occur somewhat on a tangent, and, since breaks in the dorsal and volar cortices are not superimposed on a roentgenogram, the fractures will be seen as two lines which fuse at their lateral aspect to form a ring.

In the interpretation of roentgenograms, slight malpositions were regarded as extremely suspicious even if no clear-cut breaks were seen.

PATHOLOGIC PROCESS

The pathologic changes at the site of an un-united carpal scaphoid usually depended upon the duration of the injury. If it was brief, the findings included interposed cellular fibrous tissue (*6*) and porosis of the bone, with hyperemia in the viable fragments.

If avascular necrosis of the proximal pole had already developed when the roentgenograms were made, regeneration was usually observed for at least a millimeter at the fracture surface. Changes in the joint capsule, which included fibrocystic hyperplasia and edema in the vicinity of the fracture site, were moderate. Adhesions between the synovia and the fracture line were generally more numerous when there was aseptic (avascular) necrosis of the proximal fragment; the explanation of their presence was probably the formation of new vessels to carry blood to the necrotic bone.

In nonunion of long duration, there was either a dense fibrous union or nearthrosis. In several of the 63 fractures collected from AAF regional hospitals (*6*), there was considerable motion at the fracture site, and a new joint had formed, in which there were fairly well-developed articular surfaces of hyaline tissue and fibrocartilage.

Osteosclerosis of the fracture surfaces was characteristic in nonunion. Because of some bone absorption at the fracture site, the fragments seldom fitted together accurately at the periphery. Reactive osteoarthritic changes varied from a minimal narrow margin of degeneration on each side of the fracture line to advanced changes in the articular cartilages of both the scaphoid and the radius. In three of the four fractures in the Army Air Forces series in which radiocarpal arthrodesis was necessary (*6*), there were advanced traumatic osteoarthritic changes in the form of pale yellowish discoloration of the cartilage, fibrillation, and areas of erosion.

Joint capsules were usually thickened to some degree because of fibrosis. Synovial hyperplasia with villous formation was observed but was uncommon.

Numerous old, un-united fractures of the carpal scaphoid, which had occurred in adolescence and gone unrecognized, were encountered in the Army (*11*). Changes included sclerosis of the fractured surfaces and mechanical arthritic changes in the radius, which were frequently considerable and which were manifested by angulation of the radial styloid and new facet formation in the articular surfaces.

Histopathology.—Few histopathologic examinations of fractured scaphoids were possible during the war (*13*). In three fractures treated surgically at the Regional Hospital, Fort Riley, Kans., examination of excised specimens revealed that bone obtained from the dense or sclerotic areas was, for the most part, necrotic and that rarefied (pseudocystic) areas were filled with loose granulation tissue. Portions of the articular cartilages removed in the vicinity of areas of nonunion presented clear-cut

evidence of fibrillation and degeneration. In one instance, irregular proliferation of new bone and cartilage was also observed and was taken to indicate the presence of a marginal osteophyte. Capsular tissue obtained from the scaphoid-capitate articulation showed increased vascularization and hypercellularity of the synovial lining.

Pathophysiology.—Major Obletz considered several features of fracture healing in general particularly applicable to fractures of the carpal scaphoid (*2*):

1. Stirling's studies on the immediate drop in the pH of fluids at the fracture site (*14*).
2. A reactionary hyperemia believed to be the result of the liberation of minute quantities of histamine and acetylcholine, with decalcification and osteoporosis as a further result (*15*). Of clinical importance in this connection was the fact that, if the wrist was not completely immobilized, the hyperemia was prolonged beyond the usual (2-week) period.
3. R. W. Johnson's demonstration that all cancellous-type bones heal more slowly than long bones, partly because of lack of subperiosteal callus formation and partly because in cancellous bones the reaction is less extensive and less active than is the medullary response in the diaphysis (*16*).

If the wrist was not immobilized immediately and adequately, continued movements, as already pointed out, caused a shearing stress between the fragments, and fibrous and fibrocartilaginous tissue developed at the fracture site. The bone immediately underlying the newly formed cartilaginous layer became sclerotic and eburnated, and assumed many of the characteristics of subchondral bone. The fibrocartilage itself formed an effective carrier to isolate the proximal fragment from its only source of blood supply, and avascular necrosis was the inevitable result. Roentgenologically, this process was evident by the persistence of the translucent fracture line, with its dense, white, irregular, sclerotic margin on either side of the line dividing the cancellous scaphoid into two parts. Such observations always indicated nonunion, though it did not always follow that the avascularity would be permanent.

MANAGEMENT OF FRESH FRACTURES

Principles of Immobilization

No general agreement was reached during the war—as there had been no general agreement before it—on the treatment of nonunion of carpal scaphoid fractures. There was general agreement, however, on the proper management of fresh fractures (*2, 10*).

It was imperative that the wrist be immobilized as soon as possible after the injury, that immobilization be complete, that it be uninterrupted, and that it be maintained until there was clear-cut roentgenologic evidence of healing. It was equally important that the cast be removed at intervals

of 3 or 4 weeks, roentgenograms taken, and a new cast applied. Finally, it was extremely important that the cast be replaced whenever it broke, softened, or otherwise failed to immobilize the wrist completely. This precaution was essential during the first 3 or 4 weeks after injury, when the fracture repair process was extremely delicate and required complete protection from shearing stresses.

Practical Considerations

The gauntlet or glove type of cast described by Soto-Hall and Haldeman in 1941 (*7*) was the most satisfactory form of immobilization (fig. 147). It extended from just below the elbow to the distal palmar flexion crease. The wrist was fixed in a few degrees of dorsiflexion. With a cast of this type, the fingers could be flexed into the palm; the tip of the thumb and index finger could be brought together; and since hospitalization was not necessary, the soldier could be safely encouraged to use his hand as much as possible and to participate in the training program of his group.[2]

However the wrist was put up, it was imperative that ulnar flexion be avoided (*11*). In that position, the scaphoid leaves its facet in the articular surface of the radius and moves distally and radialward, while the fractured surface tends to separate because the proximal fragment remains attached to the lunate bone by the interosseous ligaments. In radial deviation, as can be demonstrated by roentgenograms or by experimental cadaveric fractures, the fragments are closely approximated, especially when the thumb is abducted.

Management of displacements.—Carpal scaphoid fractures were not usually displaced. If they were, as demonstrable on lateral films, reduction could be effected by traction on the thumb while the surgeon molded the snuffbox digitally. Once alinement was obtained, the fragments were immobilized by placing the wrist in full radial deviation, with 20 to 30 degrees of dorsiflexion, and pressing the base of the thumb just below the proximal crease into full abduction.

Lunate dislocations had to be reduced carefully. If they were manipulated by manual pressure, a median nerve lesion was a risk. It was safer to reduce them by putting a loop around the wrist and applying 35 pounds of traction for 10 minutes. This maneuver separated the carpal bones and created a space into which the lunate bone could fall. An exception to this technique was a total dislocation of the lunate bone in which the bone lay unattached between the tendons. After reduction, the wrist was put up in slight flexion for at least 3 weeks, to prevent recurrence of the dislocation, which was likely if the wrist was dorsiflexed. After that time, the standard position was safe.

[2] Prolonged hospitalization had to be endured in some instances because some infantry unit commanders refused to accept a soldier in quarters with his hand and forearm enclosed in plaster.—M. C.

FIGURE 147.—Reduction and immobilization of carpal scaphoid fracture. A and B. Maneuver for manipulating wrist into correct position of full radial flexion, with 20 to 30 degrees of dorsiflexion, and with full abduction of first metacarpal. The heel of the surgeon's hand is pressing firmly against the heel of the patient's hand. In this position, the metacarpophalangeal and interphalangeal joints are relaxed in slight flexion. C. Site (indicated by arrow) at which pressure is applied. Patient's hand, wrist, and thumb are in correct position. D. Method of holding hand while plaster of paris is drying. The splint is carried to the metacarpophalangeal joints of the fingers and to the middle of the thumb nail. No pressure is put on the tip of the thumb. (Soto-Hall, R., and Haldeman, K. O.: J. Bone & Joint Surg. 23: 841–850, October 1941.)

If the lunate dislocation was ventral, it was advisable, after reduction, to put the wrist up in some degree of ventral flexion, to prevent recurrence.

Some observers considered reduction of a displaced carpal scaphoid unnecessary in most instances, on the ground that, even when the injury was associated with a dislocation of the lunate bone, the fragments were usually in good position.[3]

Management of the thumb.—Union seldom occurred if the thumb was not included in the cast though many orthopedic surgeons did not consider its particular position a vital matter. Some observers, on the other hand, regarded its position as of great importance for several reasons, aside from the fact that when it was included in the cast, more complete fixation of the wrist could be obtained.

1. Its position was clearly important for anatomic reasons. Any active movement of the thumb involves the long flexor tendon and the abductor pollicis. The latter structure often originates in the tubercle of the scaphoid, and abduction of the thumb, therefore, produces motion in the distal scaphoid fragment (*7*). The close relation of the long flexor of the thumb and the scaphoid could be demonstrated in experimentally produced fractures, in which it could be shown that motion of the interphalangeal joint altered the relation of the fracture surfaces. Further confirmation could be obtained by asking the patient with a recent fracture to flex the interphalangeal joint actively; this movement always caused severe pain.

As a rule, the thumb was put up in the anatomic position beyond the distal joint. Good results, however, were accomplished in other positions. At the 1943 AAF conferences (*4*), 10 hospitals reported immobilization of the thumb with the wrist in radial deviation, but five of the 10 extended the plaster to the tip of the thumb while the other five carried it to a point just proximal to the phalangeal joint. One officer thought abduction of the thumb unnecessary, but advised that it be held firmly in plaster in a neutral position and that the plaster be well molded into the palm.

Results.—The results of adherence of these principles were generally excellent. There were only three failures in 198 fresh carpal scaphoid fractures treated by them at AAF hospitals (*4*). Only 28 of Major Obletz' 45 patients remained under his observation until their casts could be discarded, but there were no nonunions in any of them and healing was progressing satisfactorily in the other 17 patients when last they were seen (*2*).

Many poor results in fresh carpal scaphoid fractures could be attributed to two mistakes in immobilization:

1. If the cast that had been applied while there was considerable swelling of the hand and wrist was not changed when the swelling subsided but was allowed to remain in situ for 6 weeks or more, while the soldier, in the meantime, was urged to exercise his fingers, nonunion was the frequent result of shearing stresses.

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[3] This reasoning does not take into consideration posterior perilunate dislocations of the carpus.—M. C.

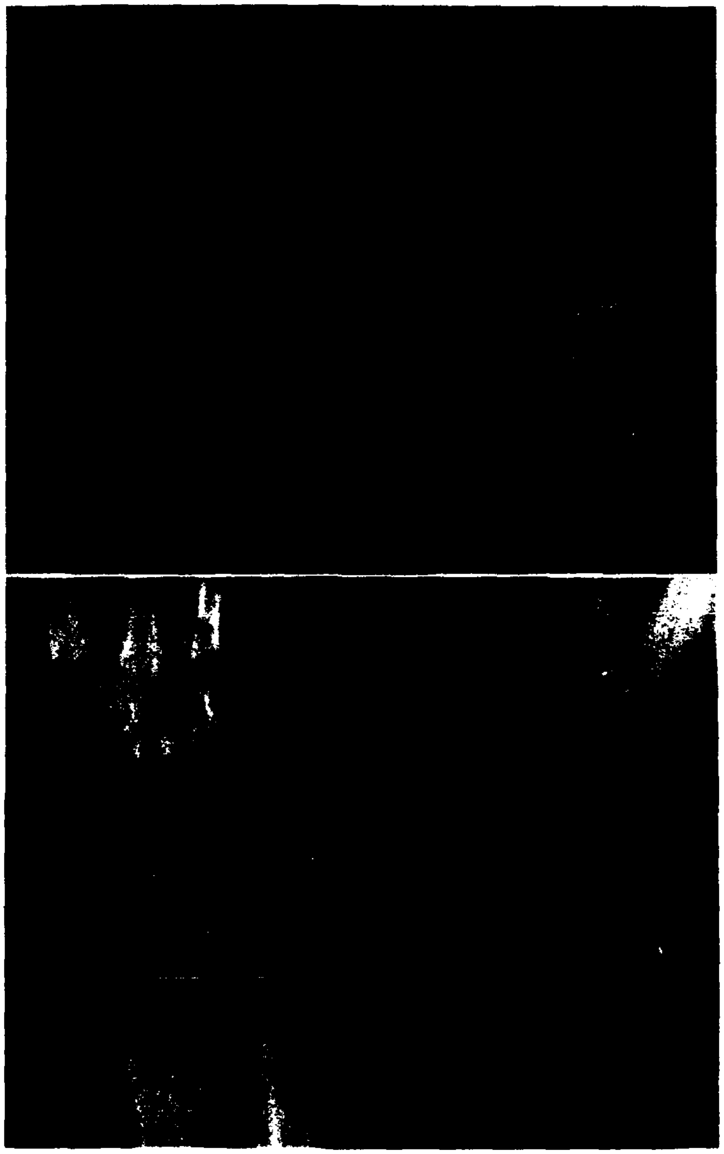

FIGURE 148.—Undisplaced fracture of carpal scaphoid and Colles' fracture of epiphyseal separation at distal radius in same wrist sustained in severe fall. (Top) Lateral and anteroposterior roentgenograms of lower forearm and wrist. The undisplaced carpal scaphoid fracture is seen as a distinct line across the waist of the bone. The radial fracture (which in the lateral view shows slight displacement) was diagnosed as a Colles' fracture but might be an epiphyseal displacement. (Bottom) Anteroposterior and lateral roentgenogram of same wrist 10 weeks later. Both radial and carpal scaphoid fractures are healed in good position. After reduction of the slightly displaced radial fracture, the forearm, wrist, and hand were immobilized in plaster, in mid position, for 6 weeks. The result was excellent and the soldier was returned to duty.

2. A more frequent reason for poor results in fresh fractures was too early removal of the cast. Its routine abandonment at the end of a fixed

period—usually 6 to 8 weeks—was often a very costly error. As already emphasized, the indication for removal of the cast should always have been complete healing of the fracture, and the criterion of complete healing should always have been complete roentgenographic disappearance of the fracture line (fig. 148).

MANAGEMENT OF UN-UNITED FRACTURES

General Considerations

When nounion occurred in a neglected or mismanaged carpal scaphoid fracture, therapy was always on an individual basis, and the orthopedic surgeon did well to remind himself that he was dealing with an extremely difficult injury. The objective of returning the symptomatic patient to full military duty was laudable but was not attained, even in the most competent hands, in enough cases to warrant much of the surgery for un-united carpal scaphoid fractures that was performed in World War II. For that reason, separation from service was often the simplest and most economical way to handle un-united fractures that made a man of limited use to the Army, particularly if his injury was not line-of-duty-yes.

Treatment of the nonunion was not always necessary. A large number of men did heavy duty throughout the war without being aware of their injuries, which often antedated their induction. Numerous roentgenograms taken at separation centers revealed apparently efficiently functioning nearthroses. Clear-cut, smooth articular cortices had formed, and, more often than not, no reactive osteoarthritic changes were evident. In many fractures discovered during the war, when firm fibrous union had resulted and there was little or no demonstrable disability, no treatment was instituted. The patient, however, was always informed of the injury; since with continued functional activity, the possibility of traumatic arthritis had to be borne in mind, as well as the possible need for later surgery.

A number of orthopedic surgeons believed that, in many instances of nonunion, a trial of immobilization was justified before more radical measures were undertaken. Good results were obtained by the plan in 10 cases reported by Major Bannerman (*3*), even though, in some instances, immobilization had been necessary for as long as 7 months, and in one instance, 9 months had elapsed from injury to the institution of immobilization. Osteoarthritic changes were not present in any of the 10 cases. Osteoporosis (Preiser's disease) was present in six cases, but proved no bar to healing.

Good motivation had a great deal to do with end results. Poor motivation combined with an un-united fracture of the carpal scaphoid was unlikely to produce a good combat soldier. Later in the war, after it became evident that a number of patients had been operated on who should not

have been, all candidates for surgery were carefully evaluated psychologically. There were two instances of postoperative anxiety states in the 63 un-united carpal scaphoid fractures studied by Major Luck and his associates (*6*). Both patients were relieved by psychiatric treatment.

Techniques

Methods of treatment of nonunion of the fractured carpal scaphoid included chiefly excisional surgery, drilling, bone grafting, and fusion. Replacement of the excised bone by a Vitallium replica was carried out in a few cases, and in a few others, the proximal row of carpal bones was excised.

Excisional surgery.—The argument for early removal of the proximal fragment of the fractured carpal scaphoid was based on Phemister's demonstration that, if avascular necrosis was present, the fragment might undergo slow creeping substitution, or its interior might be absorbed, but not replaced, by bone (*12*). The result might be adhesions, partial necrosis of the cartilage, irregularity of the articular surface, and chronic arthritis.

In spite of the risks of conservative therapy, it is evident, from what has been said earlier in this chapter, that in many instances, routine excisional surgery was far too radical. Avascularity was often temporary, and the presumably necrotic fragment regenerated, with restoration of a normal, or almost normal, range of painless motion of the wrist.

Excision of comminuted fragments of the scaphoid was often a logical plan (*2*). So was excision of the polar fragment if it represented less than 20 percent of the total size of the scaphoid. Finally, excision was sometimes employed when the proximal fragment was too small to permit the insertion of a bone graft or after a drilling operation or a grafting operation had failed.

The chief objection to excision of a large fragment of the carpal scaphoid was that, in time, the capitate bone would protrude between the lunate bone and the distal scaphoid fragment, with resulting derangement of the distal carpal row, which was one of the frequent causes of failure when this technique was used. If the proximal pole was excised, the best results were obtained when the operation was performed within the first few weeks after the injury.

Excision of the entire scaphoid was never a desirable procedure. It resulted in a weakened wrist, radial deviation of the hand, and impaired gripping power (*17*). The only indication for it was fear of prolonged immobilization following bone pegging, when arthritic changes were also present.

Drilling.—More than one orthopedic surgeon expressed the opinion that drilling was an operation that should never have been employed in military surgery. It did not stimulate osteogenesis, and it did not promote healing in even half of the cases in which it was used.

Both drilling and grafting had the same objective, to revascularize necrotic or partly necrotic bone, the sclerotic borders of the fracture, or the intervening fibrous barrier at the site of nonunion by granulation tissue derived in part from the contiguous vital portion of the scaphoid (*13*). The success of both techniques depended principally upon the potential source of the blood supply and the osteogenetic tissue derived from the contiguous living fragment (fragments) of the carpal scaphoid bone. If the estimate of the blood supply was not correct, the operation was futile. Furthermore, neither drilling nor grafting, no matter what the result, had any effect on an existing traumatic arthritis in the intercarpal region.

Bone grafting.—Early in the war, bone grafts were employed in many old nonunions in the hope of qualifying the patients for full military duty, including eligibility for flight crew training. These objectives were not often realized, and a fair number of the men had more disability after operation than they had had originally. In one particularly instructive case of bilateral un-united line-of-duty-yes fractures, a bone peg graft was inserted on the left side. At the end of a year of hospitalization, function was 45 degrees of flexion and 20 degrees of extension, and the wrist was still painful. The opposite wrist, which had been left untouched, had 80 degrees of flexion and extension and was practically painless.

By the end of the war, results of bone pegging were so unsatisfactory that the procedure had been almost entirely abandoned. The results of blind pegging, when checked by roentgenograms, frequently produced surprises. In one instance, the peg was found between the lunate bone and the proximal pole of the carpal scaphoid. Wide exposure, to permit drilling by direct vision, was not the solution of such errors; it introduced possible jeopardy of the blood supply to the scaphoid.

A bone graft was usually removed in a single section from the ilium, less often from the radius, and was employed as an inlay or was inserted into a channel across the fracture line. Another, and apparently more satisfactory, technique was to use cancellous bone grafts, which were superior to cortical grafts (p. 407). A small proximal fragment did not lend itself to this technique, and the best results were achieved with it when the fracture was at the waist of the carpal scaphoid.

Lt. Col. Abraham B. Sirbu, MC (*17*), used this technique with good results in 16 cases (fig. 149), and Major Milgram (*8*) used it in 23 fractures seen from 6 to 30 months after injury, all disabling, and all line-of-duty-yes (fig. 150). Of 18 operations done sufficiently long ago to warrant evaluation at the time of the report, 14 showed radiologic union, in three instances by bone bridges comprising, respectively, 60, 70, and 80 percent of the diameter of the scaphoid. These bridges did not necessarily extend from cortex to cortex but seemed to correspond more or less with the diameter of the cancellous core packed into the defect at operation.

In the 14 patients in the group with radiologic union, eight returned to duty after average hospitalization periods of 9½ months, most of which were spent on work furloughs. Union was attained as early as 3 months in

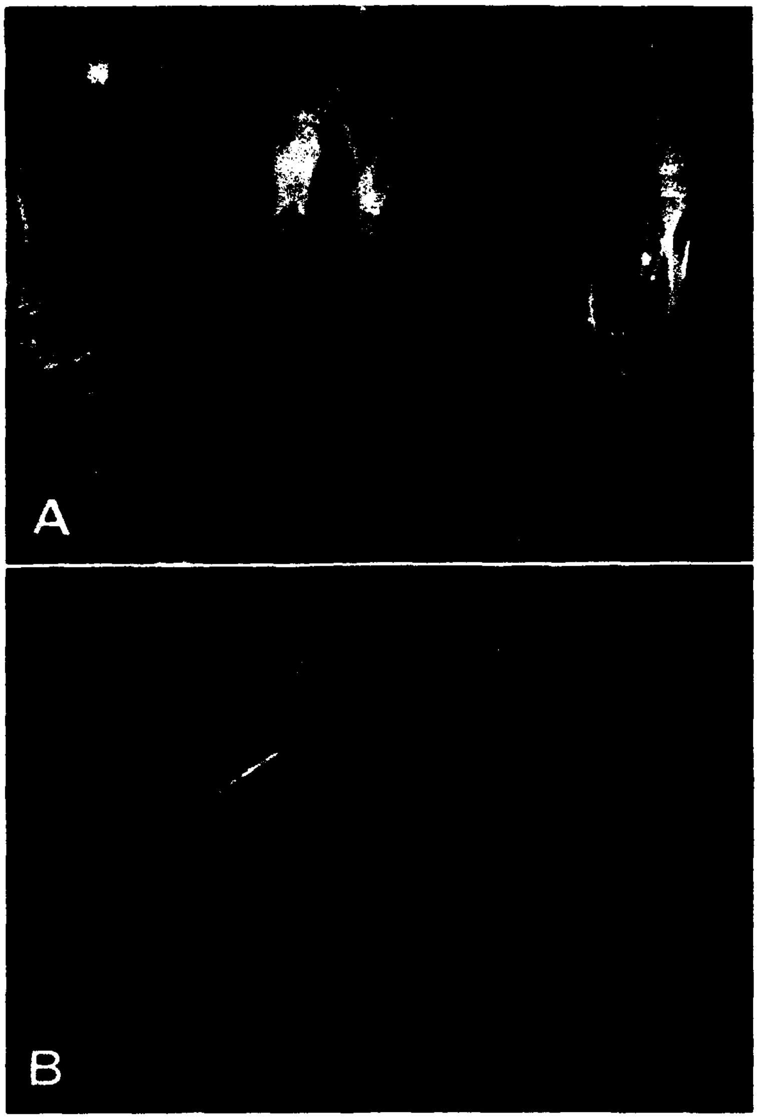

FIGURE 149.—Un-united fracture of carpal scaphoid bone with resulting painful arthritic changes indicating fusion of wrist. A. Posteroanterior roentgenogram of hand (a) showing ulnar deviation. Lateral (b) and anteroposterior (c) roentgenograms, showing un-united, fragmented fracture of carpal scaphoid bone. The radiocarpal and intercarpal joints show marked thinning of the joint spaces and eburnation of the opposing bone surfaces. These roentgenograms were made 11 months after injury. B. Lateral and anteroposterior roentgenograms of same hand and wrist 18 months after fusion operation utilizing iliac cancellous bone grafts. Bone continuity is obvious from the radius to all carpal bones except the triquetral bone and part of the hamate. At the time of this examination, the soldier had been on duty for 10 months.

some of these 14 cases, but in others, casts had to be worn for as long as 8 months. The other six patients in the series were sent to convalescent centers preliminary to return to duty after average hospitalization periods of 5 months, half of which were spent on work furloughs. Radiologic healing

FIGURE 149.—Continued. C. View of hand showing wrist in approximately 30-degree dorsiflexion, with excellent range of motion in fingers and thumb. D. Lateral view of hand with superimposed view of thumb to demonstrate further the range of motion. E. View of hand and wrist to show range of supination beyond full pronation. These photographs were taken 18 months after operation. This was an excellent functional result. (Sirbu, A. B.: Wrist Fusion Following Old Fractures of the Carpal Scaphoid. [Unpublished data.])

FIGURE 150.—Use of cancellous bone in grafts for un-united fracture of carpal scaphoid bone. (Left) Anteroposterior roentgenogram of wrist on 21 December 1944. The injury was sustained on 15 August 1943. (Right) Same, on 19 March 1945, 10 weeks after bridging of gap in carpal scaphoid with cancellous bone. The fracture is united and about 80 percent of the former fracture line is obliterated. (Milgram, J. E.: Carpal Scaphoid Nonunion Treated by Cancellous Bone Grafting. [Unpublished data.])

was evident in all of these cases, but immobilization was still considered necessary.

Three operations were classified as failures, and the remaining operation was likely to fall into the same classification.

Fusion.—The objective of wrist fusion in old fractures of the carpal scaphoid was to obtain a stable, painless joint in patients for whom more conservative types of surgery were not indicated or were not feasible. The chief indication for this operation was traumatic arthritis of such severity as to cause painful restriction of motion, weakness of grip, and other disabilities. In some instances, the arthritic changes also affected the radiocarpal and intercarpal joints.

The carpal scaphoid injury was sometimes so extensive that spontaneous fusion had occurred. If the position was good and motion painless, no further therapy was indicated. Spontaneous fusion, however, was by no means always symptomless. Three typical (and highly instructive) histories were reported by Maj. Charles J. Sutro, MC, from Fort Riley Regional Hospital (*13*). All the patients had been inducted with unrecognized carpal scaphoid fractures. All had histories of mild trauma to the wrist 10 months,

2 years, and 4 years ago respectively. None had had previous medical attention. All had had attacks of local pain and swelling, but had been able to do light work in civilian life. After several months of routine military duty, all had chronically enlarged and painful wrists, and all had reached the stage at which any sort of manual work caused severe pain. Examination in each case revealed obliteration of the normal landmarks of the wrist as the result of bony fusion, as well as persistent tenderness over the site of the fracture. Men in this condition were of little use to the Army, and the chances of making them useful by surgery were not good. Nevertheless, they were all treated by fusion of the scaphoid bone to the capitate, in an endeavor to revascularize the dead bone and encourage union. Operation was considered entirely successful in two cases in that the functional power of the hands was greatly increased and the men could now do sustained useful work in contrast to their limited preoperative activity. In the third case, of 4 years' duration, bony healing of the fractured scaphoid was still incomplete 6 months after surgery.

This same procedure was used in a fourth instance of bilateral fractures of the carpal scaphoid sustained during a troop football game. Both forearms, wrists, and thumbs were kept immobilized in plaster for 5 months. Complete healing of the fracture occurred on the right side. On the left, serial roentgenograms showed progressive resorption at the site of the fracture, with sclerosis and nonunion. To halt the pathologic process, an arthrodesis was performed between the fractured scaphoid and the capitate bone after curettage at the site of nonunion. This operation was also considered successful.

Usually good results were reported in the 18 fusions of the wrist (table 10) reported by Colonel Sirbu from Borden General Hospital, Chickasha, Okla. (*17*). Of these, nine operations were performed for combat-incurred gunshot wounds, two for crushing injuries of the wrist joint, two for severe perilunate posterior dislocations of the carpus, and the other five for ununited fractures of the carpal scaphoid with marked arthritic changes in the radiocarpal and carpal joints.

End Results

End results of surgery for un-united carpal scaphoid fractures are not generally available, but those obtained in the 63 cases collected by Major Luck and his associates may be cited as typical (*6*). The procedures included 34 cortical grafts (bone pegs and inlays), nine cancellous grafts, eight excisions of proximal fragments, six drilling operations, two total excisions of the carpal scaphoid, and four radiocarpal arthrodeses. The results to date were good in 31 cases, fair (improved) in 12, and poor (no improvement) in 20.

These evaluations were made only a few months after operation, and the chances were considered good that a long-range study might show

TABLE 10.—*Essential data in 18 fusions of the wrist for old fractures of the carpal scaphoid bone* [1]

Case No.	Date and mechanism of injury	Previous treatment	Date of hospitalization	Admission diagnosis	Date of operation; type of fusion	End-results; disposition
1	3 February 1943, fall on outstretched hand.	None	January 1944	Nonunion carpal scaphoid, traumatic arthritis.	29 February 1944; 4 August 1944; iliac grafts.	Excellent; duty November 1944.
2	1940, fall from automobile.	Bone pegging operation.	April 1944	Nonunion carpal scaphoid, traumatic arthritis.	15 May 1944, iliac grafts.	Good; duty November 1944.
3	23 March 1944, accidental gunshot wound.	Debridement and Orr dressing.	August 1944	Compound fracture scaphoid, capitate, hamate and radial styloid, traumatic arthritis.	29 September 1944, iliac grafts.	Excellent; duty February 1945.
4	12 July 1944, thrown from jeep.	Attempted reduction and cast (overseas).	February 1945	Retrolunar dislocation, nonunion of scaphoid, traumatic arthritis.	9 February 1945, iliac grafts.	Excellent; CDD [2] June 1945.
5	20 July 1944, penetrating shrapnel wound.	Debridement and Orr dressing.	January 1945	Compound fracture radius and ulna, malunion, traumatic arthritis.	20 March 1945, iliac grafts, excision distal end ulna.	Excellent; CDD October 1945.
6	25 June 1944, penetrating gunshot wound.	Debridement and Orr dressing.	January 1945	Compound fracture proximal carpal bones, traumatic arthritis.	26 March 1945, iliac grafts.	Excellent; CDD August 1945.
7	30 October 1944, penetrating gunshot wound.	Debridement and Orr dressing.	January 1945	Compound fracture scaphoid, triquetrum, both multangulars, traumatic arthritis.	28 March 1945, iliac grafts.	Excellent; CDD August 1945.
8	29 August 1944, crushing injury.	Excision of lunate, 16 October 1944 (overseas).	March 1945	Dislocation lunate, fracture radial and ulnar styloids, traumatic arthritis.	4 April 1945, iliac grafts.	Excellent; CDD August 1945.
9	24 May 1944, penetrating shell fragment wound.	Debridement and Orr dressing. Subsequent drainage of osteomyelitis of distal end radius.	September 1944	Compound fracture distal end of radius, osteomyelitis, marked radial deviation of hand.	9 April 1945, iliac grafts, resection distal end ulna, correction of deformity.	Excellent; ready for CDD October 1945. Still hospitalized for another condition.
10	September 1943, wrist crushed by falling logs.	Splint 2 weeks	March 1945	Fracture with nonunion carpal scaphoid, traumatic arthritis.	18 April 1945, iliac grafts.	Good; CDD August 1945.
11	19 November 1944, penetrating shell fragment wound.	Debridement and Orr dressing.	January 1945	Compound fracture, scaphoid, lunate and radial styloid, traumatic arthritis.	7 May 1945, iliac grafts.	Excellent; CDD August 1945.
12	2 February 1945, penetrating shell fragment wound.	Debridement and Orr dressing.	March 1945	Compound fracture distal end of radius, shortening, radial deviation of hand.	21 May 1945, iliac grafts, resection distal end ulna.	Good; CDD September 1945.

13	19 December 1944, blow by falling box.	Reduction, splinting....	April 1945	Unreduced posterior dislocation of wrist, fracture radial and ulnar styloids.	23 May 1945, iliac grafts, resection distal end ulna.	Excellent; ready for CDD 15 October 1945. Still hospitalised for another condition.
14	1 December 1945, fall on outstretched hand.	Cast 3 months, returned to duty.	May 1945	Nonunion carpal scaphoid, traumatic arthritis.	21 August 1945, iliac grafts.	Satisfactory progress of fusion; still under treatment (1 November 1945).
15	31 March 1945, penetrating gunshot wound.	Debridement and Orr dressing.	June 1945	Compound fracture all carpal bones, shortening and disorganisation of wrist.	22 August 1945, iliac grafts.	Satisfactory progress of fusion. Still in cast; still under treatment (1 November 1945).
16	21 March 1945, crushing injury in jeep accident.	Debridement and Orr dressing.	June 1945	Compound fracture radius, with shortening and radial deviation of hand.	2 October 1945, iliac grafts, resection distal end ulna.	Fusion progressing, deformity corrected. Still in cast; still under treatment (1 November 1945).
17	10 August 1944, shell fragment wound.	Debridement and Orr dressing.	January 1945	Compound fracture distal radius, scaphoid and lunate, traumatic arthritis.	5 October 1945, iliac grafts.	Too early to state. Still in cast; still under treatment (1 November 1945).
18	20 September 1944, blow by enemy rifle butt.	Self-applied splint 4 weeks (POW).	October 1945	Nonunion carpal scaphoid, traumatic arthritis.	19 October 1945, iliac grafts.	Too early to state. Still in cast; still under treatment (1 November 1945).

[1] Results were classified as excellent when there was clinical and roentgenologic evidence of solid fusion of radiocarpal and intercarpal joints, normal finger motion, good rotation of forearm, retained motion in carpometacarpal joints, a painless wrist, and satisfactory grip. Results were considered good when the criteria listed were met but the patient had some discomfort on use of the extremity, moderate impairment of the gripping power, and only a trace of motion in the carpometacarpal joints.

[2] Certificate of Disability for Discharge.

Source: Sirbu, A. B.: Wrist Fusion Following Old Fractures of the Carpal Scaphoid. [Unpublished data.]

somewhat better results. The tendency was to complain of fewer symptoms after discharge from service and return to civilian life, when secondary gains ceased to be a factor in the situation—except when disability had to be perpetuated to maintain a pension at its current level.

At any rate, the discouraging results in these 63 delayed cases are in striking comparison to the excellent results (good in 195 of 198) in fresh fractures which were recognized promptly and treated without delay in AAF hospitals staffed with well-qualified orthopedic surgeons (*4*). It is significant that, in the estimate of results to be anticipated from surgical procedures in old un-united fractures of the carpal scaphoid, the most experienced orthopedic surgeons were the most pessimistic.

POSTWAR SURVEY

Materials and Methods

The World War II experience with carpal scaphoid fractures was sufficiently impressive in terms of unsatisfactory results and loss of mandays to justify a postwar study of end results (*1, 18*). The survey was carried out at the Massachusetts General Hospital, Boston, Mass., sponsored by the Subcommittee on Orthopedic Surgery, National Research Council, and aided by a grant from the Veterans' Administration.

The study included:

1. The collection of a bibliography of 804 (numbered) references, covering well over a hundred years, beginning with 1841 (reference No. 10).
2. A followup study of 44 men living in the vicinity of Boston who had had recognized fractures of the carpal scaphoid while they were in military service. All had sustained their injuries at least 4 years earlier. They were examined comprehensively by orthopedic, psychiatric, ergographic, and roentgenologic methods. The original goal of studying at least 200 men was not realized because the necessary diagnostic rosters could not be secured.
3. A statistical study of the incidence of carpal scaphoid fractures in the Navy for the years 1942–44 inclusive, and of a 20-percent sample of similar injuries in the Army in 1944.

Statistical Data

The following statistical data were secured from this analysis:

1. The incidence of carpal scaphoid fractures in the Army was 48.6 per 100,000 men per year. In the Navy, it was 40.8 per 100,000 men per year. The difference was not regarded as statistically significant.
2. It was estimated that about 16,000 carpal scaphoid fractures had occurred in the Armed Forces during World War II. These injuries, which were by far the most common fractures of the carpal bones, accounted for 69.8 percent of all carpal fractures.
3. The peak incidence was in the age group of 20–24 years.
4. The noneffective time in 66.7 percent of Army patients was 3 months or less. The fact that a third of the men with such injuries lost more than 3 months' time from

active duty indicates how serious such a fracture is from the manpower standpoint, even though it involves only a small bone of the wrist.

5. It was not possible to secure exact figures for the number of veterans who were receiving compensation for disabilities caused by these fractures, but it could be determined that, in 1946, at least 3,100 World War II service-connected disability claims were being paid for limitation of the motion of the wrist. In view of the figures just stated, it can fairly be presumed that the majority of these claims resulted from fractures of the carpal scaphoid.

Clinical Observations and Conclusions

The following observations were made, and the following conclusions derived, from this followup study of 44 former servicemen:

1. The mechanism of the injury was usually a fall on the outstretched hand. Only three of the 44 men received their injuries under combat conditions.

2. The immediate postinjury physical findings were pain, weakness, swelling, limitation of motion, and local tenderness.

3. Although the left wrist was more frequently injured than the right in this small series, no particularly significant relation was evident between the injured side and the dominant hand.

4. In 29 of the 41 noncombat injuries, the diagnosis was established within 24 hours. In the other 10 cases, either the men did not report for examination at once, or, if they did, they were told that they had sprained wrists.

5. The usual treatment was immobilization of the wrist and thumb in a plaster gauntlet. The fracture was not manipulated.

6. In these 44 cases, union occurred in every instance (29) in which the fracture was recognized promptly and treated adequately. Proper treatment led to primary healing, and, when primary healing occurred, anatomic, functional, and economic results were good or perfect.

7. There were 15 instances of nonunion, in 10 of which only conservative measures were used. Of the five patients treated surgically, only two obtained union and a satisfactory result. The other three operations were classed as surgical failures. The factors tending to produce nonunion were delay in instituting treatment and insufficiently prolonged immobilization.

8. If nonunion of a carpal scaphoid fracture persisted for a considerable period of time, anatomic and pathologic changes occurred, including partial absorption, displacement, and fragmentation of the bone; cyst formation; degenerative arthritic changes of adjacent joint surfaces; and functional ailments in the form of pain, limitation of motion, and weakness of grip. Functional impairment of this sort was present in all instances of nonunion in this series, though earning capacity was impaired in less than half of them.

9. It was concluded that, if nonunion of an old carpal scaphoid fracture is established before a man is inducted for service, it should disqualify

him. It is highly unlikely that he could complete a satisfactory tour of duty, since about 50 percent of all men with un-united fractures must be separated from service because of limiting symptoms.

Special Studies

The following special studies were carried out in these 44 cases:

1. Psychiatric studies were carried out in 39 cases. Each man was given a standard interview and completed a self-administered questionnaire covering his character, traits, and symptoms. Personalities were then compared and the results were tabulated in four categories; namely, accident-proneness, impulsivity, neuroticism, and general adjustment. The personalities were found to be heterogeneous, and no particular trait was outstanding in the group. In only six instances were clearly discernible psychologic factors related either to the clinical picture of the fracture or to the veteran's adjustment following the injury.

2. An especially designed ergograph was used to determine the comparative work capacity of the injured and uninjured wrists. The results of these tests were then compared with the anatomic (roentgenologic) and functional ratings. In general, fractures which had healed primarily produced little or no impairment of work capacity. On the other hand, work capacity was normal in only one of the 15 wrists in which nonunion was present.

The ergographic tracings in uncooperative subjects showed characteristic changes. This method of testing yielded valuable information concerning the work capacity of the injured wrist and also aided in detecting lack of cooperation by those taking the test.

3. Roentgenologic examination included five standard projections of the involved wrists and, for comparison, of the normal wrists. Although all views yielded useful information, three were especially valuable:

a. The posteroanterior view with the wrist in ulnar deviation. In this position, the scaphoid bone is laid out at greater length, the adjacent joints are widened, and in both, fresh injuries and old un-united fractures fragments tend to be spread apart.

b. The oblique posteroanterior view, with the hand in neutral position, the ulnar side down, the fingers in comfortable flexion, and the wrist rotated to a position of 45-degree pronation, so that the volar surface is at an angle of 45 degrees to the plane of the film. This position provides a true posteroanterior view of the carpal scaphoid.

c. The oblique posteroanterior view, with the hand in neutral position, ulnar side down, and the wrist supinated until the dorsal surface forms an angle of 45 degrees with the plane of the film. This position provides a true lateral view of the carpal scaphoid.

Fractures in which primary union had occurred showed little or no trace of the original injury in roentgenograms taken 4 years or more later. In marked contrast to the excellent anatomic results in primary union were the severe changes noted in every instance of nonunion; they included avascular necrosis, cyst formation, fragmentation and displacement of the scaphoid, and sclerosis and narrowing of adjacent joints.

The data and conclusions of this postwar report coincide with remarkable fidelity with the data and conclusions of orthopedic surgeons who handled carpal scaphoid fractures during World War II.

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Part VI

REGIONAL FRACTURES: LOWER EXTREMITY

CHAPTER XXI

Injuries of the Pelvis and Hip

Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

Section I. Fractures of the Pelvis

NONCOMBAT INJURIES

Simple Fractures

The most frequent simple noncombat fractures of the pelvis involved the anterior-inferior or anterior-superior rami of the pubis. The displacement of the fragments was usually slight, and the only treatment necessary was recumbency on a hard bed for 4 to 8 weeks.

Simple fractures of the pelvis involving the anterior-superior or anterior-inferior iliac spine were treated by recumbency, with the affected hip in flexion. Fractures involving the tuberosity of the *ischium* were similarly treated, but with the hip in neutral position. Functional recovery in about 3 months was the rule. All three types of fractures resulted from strenuous physical activity in combat training or in actual combat.

If fractures of the pelvis were associated with fracture-dislocations of the sacroiliac joint or the posterior ilium, treatment consisted of traction applied to both legs or the application of well-fitted leg casts, with a spreader between them.

Compound Fractures

Many severe compound fractures of the pelvis were encountered in the Zone of Interior. They were often serious in themselves and they were always potentially serious because they occurred in cancellous bone, which is highly susceptible to infection.

Training Injuries

Fractures of the pelvis during training were usually the result of traffic accidents and vehicular wrecks. They were frequently associated

with urinary tract injuries and complications, in the treatment of which the urologic service always participated.

Patients with displacements were treated by skeletal traction. A large amount of weight was necessary if the entire side of the pelvis had been displaced upward or if the head of the femur had been driven into the acetabulum. Consistently good results were obtained at the Regional Hospital at Camp Swift, Tex., by using simple skeletal traction on one leg and adhesive traction on the other, to stabilize the patient in bed (*1*). Spreading of the pelvis, which was not usual, was corrected by a pelvic sling.

Several Malgaigne's fractures were encountered at this same hospital, with upward displacement of half of the pelvis. A satisfactory anatomic result was obtained in each instance.

Other Noncombat Injuries

Subluxation of the sacroiliac articulation was always a serious injury. It often required manipulation, followed by immobilization in a plaster spica for 2 or 3 months. If pain persisted because of instability of the joint or development of traumatic arthritis, arthrodesis was necessary.

Laterial crushing injuries, such as occurred when the victim was caught between two vehicles, often resulted in double fractures of the pelvic ring, with the pubic portion most likely to be involved. Displacement of fragments was limited by their muscular attachments. Recumbency for 6 to 8 weeks usually resulted in functional recovery.

Anteroposterior compression of the pelvis might result in dislocation of the sacroiliac articulation and disruption of the symphysis pubis. Dislocation of one of these joints was sometimes associated with a fracture near the other joint. A dislocation of the sacroiliac joint, for instance, might be accompanied by fractures of both pubic rami. Manipulative measures, with the patient lying on the uninjured side, followed by plaster immobilization for 8 to 12 weeks, as recommended by Watson-Jones, was the usual method of management.

Injuries of the urinary tract associated with fractures of the pelvis caused by crushing injuries were always potentially serious.

COMBAT-INCURRED INJURIES

Compound fractures that were the result of enemy action were often complicated by wounds of the pelvic or abdominal viscera, or both, the management of which had necessarily been the first consideration overseas. It was the policy to bring these patients to Zone of Interior hospitals as soon as they could tolerate transportation. Transportation was in a plaster

spica. Immobilization was particularly important when the injuries involved the innominate bone, the hip joint, or the head and neck of the femur.

When the patients were received in the Zone of Interior, infection was fairly frequent. The fractures were often severely comminuted, with serious disturbances of the blood supply, but the infection was more often the result of the associated visceral injuries than of the bony pathologic processes.

These patients were received at Walter Reed General Hospital, Washington, D.C., whose experience may be considered typical, at periods varying from 7 weeks to 11 months after injury. The degree of infection was, in most instances, related to the time that had elapsed since injury. Very few patients were able to tolerate definitive treatment at once. Patients with infected injuries had moderate, or large, amounts of purulent drainage from the hip. The adjacent soft tissues were reddened, indurated, swollen, painful on palpation, and abnormally hot to the touch. Constitutional manifestations included low blood pressure; increased pulse rate; spiking septic temperature; and decreases in the red blood cell, hematocrit, and hemoglobin values. The patients' general appearance and apprehension left no doubt of the seriousness of the infection. Cultures revealed a wide variety of organisms, including, among others, *Staphylococcus aureus* and *albus*, of both the hemolytic and nonhemolytic varieties; *Streptococcus*, also including both the hemolytic and nonhemolytic varieties; and *Proteus vulgaris*. Combined infections were frequent.

Patients in this condition obviously required extremely careful preoperative preparation (p. 451) before their visceral injuries could be cared for, and these injuries, as a rule, had to be treated before definitive orthopedic treatment could be undertaken.

Most compound fractures of the pelvis were treated in body casts, not with the expectation that the casts would immobilize the pelvis, but to immobilize the extremities and promote healing of damaged tissues. In the 715 fractures of the pelvis without involvement of the hip joint collected from 16 general hospitals by Maj. T. Wiley Hodges, MC (*2*), open reduction was necessary in only three instances, in all of which results were good, and sacroiliac or lumbosacral arthrodesis was required in only four, with good results in three cases and a fair result in the fourth.

Rupture of the bladder or urethra, or injury to the ureter, occurred in 96 of the 715 pelvic fractures just mentioned, a somewhat smaller incidence than one might expect from the regional anatomy. In all such cases, immediate suprapubic cystostomy, with the insertion of an indwelling catheter and drainage of the prevesical space, took precedence of manipulation of the fracture. A fracture involving the pubic bones, however, was reduced as soon as the patient's condition permitted, so that the soft tissues in the anterior pelvic cavity, which were held apart by the displaced fragments, might return to their normal position.

Section II. Injuries of the Hip

NONCOMBAT INJURIES

Dislocations

General considerations.—The largest number of noncombat injuries of the hip joint followed truck, jeep, and other vehicular accidents. The small jeep, with its great maneuverability and high speed potential, was responsible for many such injuries, and the so-called jeep fracture became so important, in fact, that a considerable portion of the volume on orthopedic surgery in the European theater in this historical series is devoted to it (*3*). The injuries on which this particular chapter is based occurred overseas, but their mechanism and management were the same in the Zone of Interior, and the reader's attention is directed to this account.

In addition to this type of fracture, which was a World War II development, fractures and dislocations of the hip joint were much more frequent than in previous wars because of the greatly increased mechanization of the Armed Forces.

In the early years of the war, while millions of men were being trained for combat duty, simple fractures of the hip were the injuries most frequently encountered. In the last 2 years, compound fractures as the result of enemy action were observed with increasing frequency.

At the Army Air Forces conferences held in the fall of 1943 (p. 81), attention was called to the fact that, in Army Air Forces hospitals, traumatic dislocations of the hip were far more frequent than fractures, which at that time constituted no special problem (*4*). It seemed significant that, in one recent report of 366 fractures of the hip observed in civilian practice, only 34 patients, 9 percent, were between the ages of 18 and 45 years, the age limits for induction into the Army.

Because of the circumstances, fractures and dislocations sustained in the Zone of Interior could usually be treated promptly. In spite of this highly favorable factor, however, these injuries were always serious. They required long periods of hospitalization, and even when end results were good, return to duty was seldom feasible. Whether the dislocation was anterior, posterior, or inferior, the local circulation was always damaged. With the tear or rupture of the ligamentum teres and the capsular attachments, the total blood supply to the head and neck of the femur was impaired, and avascular necrosis of the head of the femur and the acetabulum could be anticipated, as well as the development of traumatic arthritis in the same structures (*5–7*).

The force necessary to dislocate a hip often, by its violence, caused other injuries, whose severity gave them priority over orthopedic management.

The civilian experience was that, if patients with dislocations of the hip without associated fractures were followed up for 5 years, from 30 to 35 percent would present changes in the head of the femur and the acetabulum, no matter how good the immediate reduction had been. Changes appeared much earlier in military than in civilian patients, probably because of the greater activity required in military life. The general policy was to watch military patients for 6 months after injury, to note possible changes. Whether or not they were apparent by this time, the most efficient plan was to retire these men or to discharge them on a Certificate of Disability for Discharge.

Dislocations were usually unilateral, although Lt. Col. James J. Callahan, MC, Consultant in Orthopedic Surgery, Fourth Service Command, observed three bilateral injuries in hospitals of that command. He encountered no inferior dislocations but did observe two anterior injuries, a very uncommon variety. Both were the result of severe trauma, both patients were in shock, and one died.

At Walter Reed General Hospital, Lt. Col. Leonard B. Barnard, MC, observed 14 dislocations, two of which were bilateral, two central, and eight posterior (*8*). The two central dislocations resulted in ankylosis, moderate deformity, and considerable shortening, but weight-bearing was painless.

In addition to associated fractures, which are discussed separately, and avascular necrosis, already discussed, *injury to the sciatic nerve* was a fairly common and always serious complication. In posterior dislocations, the sciatic nerve lies directly in the path of the dislocating head of the femur, and it is surprising, in view of the violence just referred to, that it was not damaged more often. The incidence of injury to it at Finney General Hospital (Thomasville, Ga.), three injuries in 14 dislocations, as reported by Maj. (later Lt. Col.) Everett I. Bugg, MC, may be assumed to be fairly typical (*9*). All three patients showed weakness or paralysis of the dorsiflexors of the foot, and in each instance, recovery was slow and incomplete.

Management.—Most uncomplicated dislocations of the hip responded well to management by traction. Some orthopedic surgeons preferred the manipulative technique advocated by Allis, followed by immobilization in a plaster cast or simple recumbency, with the legs held in adduction by bandages. Most patients were not permitted to bear weight earlier than 5 months after injury, although it was the common practice to permit them up on crutches in about 6 weeks and to use an ischial weight-bearing caliper after another 2 weeks.

Reduction of the dislocation by the Stimson technique was used successfully at Finney General Hospital when there was an associated injury of the central nervous system, when adequate anesthesia was contraindicated because of other injuries, or in other special circumstances (table 11).

TABLE 11.—*Final results in 12 dislocations of the hip treated by manipulation and reduction at Finney General Hospital, Thomasville, Ga.*

Case No.	Age	Etiology	Associated fractures	Complications	Treatment	Non-weight-bearing period (in months)	Follow-up (in months)	Final results
1	25	Fall from reconnaissance car.	....	Fracture, posterior lip acetabulum.	Manipulation, reduction.	5	6	Full motion. No pain on walking. Some discomfort on prolonged weight-bearing.
2	31	Truck accident......	Fracture femur, same side.	Comminuted fracture lip acetabulum.	Manipulation, reduction, traction, cast.	9	10	Full motion. . No pain, but some discomfort on prolonged weight-bearing.
3	25	Truck accident......	....	Fracture posterior lip acetabulum. Partial paralysis sciatic nerve.	Manipulation, reduction.	3½	6	Fair motion. Some discomfort on weight-bearing. Slight limp. Weakness of muscles supplied by common peroneal nerve.
4	26	Jeep accident........	....	....	Manipulation, reduction.	5	14	No pain. Almost full motion. Able to play golf without discomfort.
5	43	Auto accident	....	Fracture posterior lip acetabulum. Generalized hypertrophic arthritis, mild.	Manipulation, reduction, cast 3 months.	8	20	Some soreness of hip after prolonged weight-bearing. Slight limitation of flexion and external rotation.

6	21	Jeep accident	Fracture tibia and fibula, same side.	Chip fracture head femur.	Manipulation, reduction.	5	11	Full range of painless motion, except 50 percent limitation of internal rotation. Some pain on prolonged weight-bearing.
7	55	Simple fall	Fracture tibial condyle.		Manipulation, reduction, cast.	6	23	No pain on walking. No limp. Full motion. Occasional pain and instability of knee.
8	23	Truck accident		Fracture greater trochanter.	Manipulation, reduction, cast.	5	24	No pain. No limp. Full motion.
9	20	Truck accident	Fracture pelvis, incomplete.		Manipulation, reduction, bed rest.	2	7	Slight limitation of abduction and internal rotation. Discomfort in hip only on prolonged weight-bearing.
10	22	Jeep accident		Fracture posterior lip acetabulum. Partial paralysis sciatic nerve.	Manipulation, reduction, cast.	5	11	Limitation of abduction. Pain in hip after walking more than 1 mile.
11	19	Truck accident			Manipulation, reduction, bed rest.	2	6	Discomfort in hip region on prolonged weight-bearing. Full motion.
12	21	Truck accident			Manipulation, reduction, bed rest.	2	8	Slight discomfort in hip on prolonged weight-bearing. Slight limitation of abduction and internal rotation.

Fracture-Dislocations

Most fracture-dislocations were of vehicular origin, and the dislocation could usually be reduced, but the rim of the acetabulum was particularly susceptible to circulatory damage, and avascular necrosis and arthritic changes were frequent and might occur, in spite of immediate good results, as late as 5 years after injury. Arthroplasty or arthrodesis was usually required in these cases, followed by separation from service on Certificate of Disability for Discharge.

An uncommon and extremely serious type of fracture-dislocation was dislocation of the femoral head from the socket combined with a fracture through the neck of the femur. Patients with such an injury were usually in shock and required intensive resuscitation. Tibial or low femoral skeletal traction was attempted in some cases; but, if it failed, the preferred treatment was open operation, removal of the dislocated head, the Whitman reconstructive procedure with downward displacement of the greater trochanter, and location of the femoral neck within the socket.

Traumatic dislocations of the hip were sometimes complicated by marginal fractures of the femoral head. If, after reduction of the dislocation a loose fragment of the head interfered with motion of the hip joint or irritated the sciatic nerve, its excision was indicated.

At the 1943 Army Air Forces conferences (*4*), there was general agreement that, when dislocations of the hip were associated with fractures of the posterior margin of the acetabulum, the dislocation should be reduced and the fragment of the acetabulum, if it remained displaced, should be handled by open reduction and internal fixation.

There was much less agreement on the subject of weight-bearing. One surgeon recommended no weight-bearing for at least 4 months. Another suggested immobilization in plaster for 7 to 10 days after reduction of the dislocation, followed by motion in a bivalved cast and, then, by weight-bearing 5 weeks after the injury. One hospital reported good results in five patients permitted to bear weight at 8 weeks; their status was checked by serial roentgenograms, which showed no adverse changes in the head of the femur.

The orthopedic surgeon at one of the hospitals in the study reported nonunion in eight of 12 fractures of the neck of the femur in which weight-bearing was permitted 3 months after injury. Internal fixation had been carried out in some of these cases. This same hospital reported collapse of the femoral neck 2 years after dislocation of the hip. Most surgeons believed that the safest plan in all dislocations of the hip, with or without associated fractures of the acetabulum and the head and neck of the femur, was the protective precaution of an ischial weight-bearing splint.

In the collected material studied by Colonel Hodges from 16 general hospitals in the Zone of Interior, weight-bearing in associated fractures of the acetabulum was not permitted for periods varying from 6 weeks to 6 months, with 11.3 weeks considered optimum (*2*). In fractures of the head

of the femur (in which category some correspondents included the femoral neck), the limits were 2 to 6 months, with 15.8 weeks considered optimum. In uncomplicated dislocations of the hip, the range was 3 weeks to 12 months, with 4 months considered optimum. Orthopedic surgeons "evinced great respect" for these injuries, and it was emphasized in many replies that repeated examinations were necessary to make sure that weight-bearing was not permitted if avascular necrosis was developing.

Colonel Shands regarded the longer periods advocated as safer, but strongly advocated motion in 2 or 3 weeks if the acetabulum was not fractured, and in 8 to 10 weeks if it was.

Old unreduced fractures taxed the ingenuity of the orthopedic surgeons. Often there was nothing left to do but make the best of a bad situation. The method of choice was skeletal traction to relax the soft tissues and gain length, followed by open reduction. If this technique was unsuccessful, stabilization by fusion was the best procedure in unilateral dislocations and some type of shelf operation in bilateral injuries.

CASE HISTORIES

The following case histories illustrate some of the problems encountered in the management of dislocations and fracture dislocations of the hip in World War II.

Case 1.—A 26-year-old technician, fourth class, was admitted to Bruns General Hospital, Santa Fe, N. Mex., on 7 September 1945, an hour after he had sustained injuries of the head and right lower extremity in an automobile accident (*11*). After he had been brought out of shock and multiple lacerations of the scalp and face, which were bleeding severely, had been sutured, examination of the right leg showed it to be held in internal rotation, flexion, and adduction, with shortening of about an inch. Russell traction was applied. Because of the concussion syndrome present, it was not until the fifth day that roentgenograms of the pelvis were possible. They showed a dislocation of the head of the right femur; it was displaced laterally, and its upper margin extended about 1 centimeter above the margin of the acetabulum, though apparently it was still within that structure. An oval bony shadow, about 1 by 4 centimeters, just above the lateral border of the acetabulum, was interpreted as a portion of the posterior acetabular rim.

On 14 September, when it became evident that reduction of the dislocation was unlikely to be accomplished by continuation of traction, reduction was undertaken by manipulation and carried out without difficulty. Serial roentgenograms, however, showed no improvement in the position of the displaced acetabular rim. By 2 October, the patient's condition had improved sufficiently to permit major surgery. Through an anterior approach, the displaced acetabular fragment was identified and its position was improved, but, because of the extreme displacement and the depth at which the fragment lay, it could not be manipulated into proper relation with the ilium. Traction was continued. Subsequent roentgenograms showed the position of the fragment improved, though it was not completely replaced.

Comment.—While an anterior approach to the hip joint is usually satisfactory, in this particular instance, a posterior approach would have

FIGURE 151.—Multiple injuries of pelvis and hips plus other injuries sustained in glider crash. (Top) Anteroposterior roentgenogram of pelvis and both hips showing upward dislocation of both hips, with comminuted fragments of acetabulum on left. (Bottom) Anteroposterior roentgenogram of same pelvis and hips. On the left, the superior and posterior fragments of the acetabulum have been fixed with screws to form a shelf, while on the right the femoral head is in the false acetabulum. (Bugg, E. I.: Dislocations of the Hip. [Unpublished data.])

been simpler and would have permitted better reposition of the fractured acetabular rim (*11*).

Case 2.—A 24-year-old Army Air Forces captain was admitted to Finney General Hospital on 24 October 1944 after a glider crash overseas on 24 July, in which he sustained multiple severe lacerations and contusions, cerebral concussion, compound comminuted fractures of both tibiae, a compound fracture of the right patella, a simple fracture of the left ulna, a simple dislocation of the head of the left radius, and posterior dislocations of both hips with severe fractures of the posterior portions of both acetabula (fig. 151) (*9*). There was also partial paralysis of the right sciatic nerve.

Examination of the overseas medical record showed that there had apparently been no effort at any time to reduce the dislocations of the hips, though various manipulations and one open reduction had been performed on the other fractures.

Skeletal traction, followed by open reduction of both acetabular fractures, was carried out as soon as the patient was received in the Zone of Interior hospital, but stable reduction could not be obtained. A moderately stable false acetabulum, however, formed on the right, while on the left, it was possible to use the fractured fragment of acetabulum to form a shelf. Stability of both hips was thus achieved, although motion was greatly limited in all directions and the gait was permanently and severely impaired. The plan for future management included rotation and abduction osteotomies, probably with fusion of one hip.

Comment.—The absolute necessity of early reduction of dislocated hips is vividly illustrated in this case, in which this principle was violated. The far better results of early reduction are illustrated in table 11. With delay, a good functional result is precluded for several reasons, one of them loss of healthy cartilage over the femoral head. In such cases, the plan of attack must include acceptance of ankylosis, with later arthroplasty or stabilization by bifurcation or osteotomy (*9*).

Case 3.—A 25-year-old private, first class was admitted to Torney General Hospital, Palm Springs, Calif., on 24 July 1945, complaining of deformity and instability of the right hip, great weakness of the right lower extremity, and numbness of a portion of the lower third of the right leg and foot. He had been injured in India on 30 March, in a weapons-carrier accident. At a forward hospital, he was treated for shock, a fracture-dislocation of the pelvis, a posterior-superior dislocation of the right hip, a transverse fracture of the middle third of the shaft of the right femur, and right sciatic palsy. He was kept in skeletal traction through the distal femur for 65 days. Attempts to reduce the dislocation of the hip by manipulation were futile.

When this patient was examined at Torney General Hospital (fig. 152), he was found to present the shortening and internal rotation deformity typical of posterior-superior dislocations of the hip. The femoral fracture site was relatively stable, but motion could still be produced in this area. Hypesthesia approaching anesthesia could be demonstrated over the posterior surface of the lower third of the right leg, the heel, the entire sole, and the dorsum of the lateral four toes. Marked weakness of the hamstring muscles and of the gastrocnemius and soleus was also noted.

In September 1945, after adequate union of the fracture of the shaft of the femur had been obtained, open reduction of the dislocated right hip was carried out, with reduction and internal fixation of the posterior acetabular fracture by means of a metal screw. The femoral head, which was lying in the great sciatic notch, showed avascular necrosis, which was also demonstrable by histologic examination of sections of articular cartilage and subchondral bone. Vitallium cup arthroplasty was carried out, in the belief that it offered the best chance of a satisfactory result.

Immobilization, which was considered necessary for healing of the fracture of the posterior acetabulum, as well as to encourage revascularization of the femoral head, was accomplished by a low one-and-a-half plaster spica.

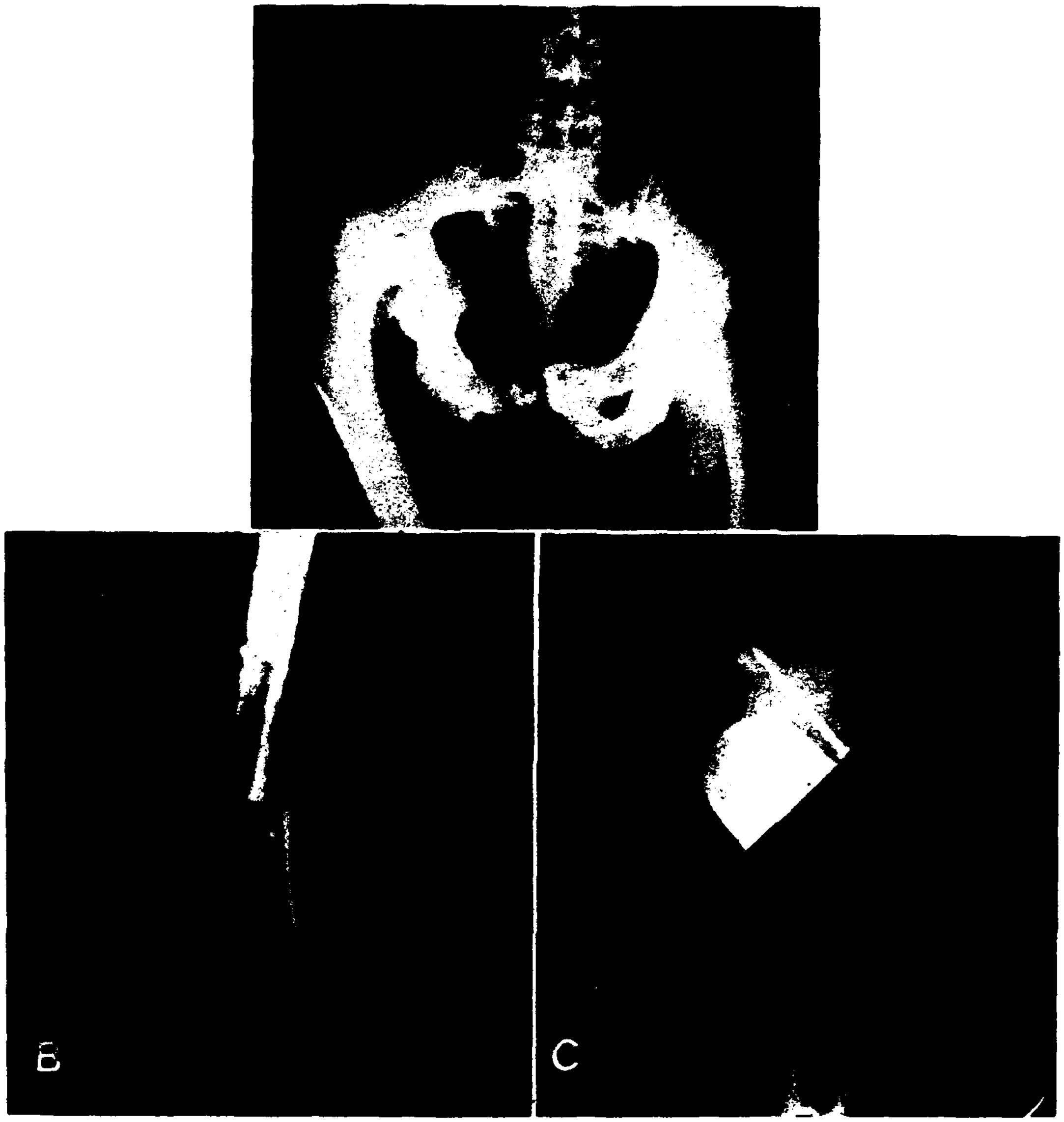

FIGURE 152.—Fracture-dislocation of pelvis, dislocation of right hip, and associated fracture of mid shaft of femur (case 3). A. Anteroposterior roentgenogram of pelvis showing fractures of both pubic bones and right acetabulum with upward dislocation of entire right side of pelvis and superior posterior dislocation of hip. B. Anteroposterior roentgenogram of right femur showing mid-shaft fracture uniting with abundant callus. C. Anteroposterior roentgenogram of right hip and right side of pelvis after (a) reduction and fixation with metal screw of posterior lip of acetabulum and (b) Vitallium cup arthroplasty of severely damaged hip joint. (Fischer, F. J.: Fracture of the Pelvis and Around the Hip Joint. Case Reports. [Unpublished data.])

The hypesthesia of the right leg and foot improved immediately after operation, and a month later, almost normal sensation was present.

FIGURE 153.—Bilateral dislocation of hips as result of jeep-truck accident in blackout (case 4). A. Anteroposterior roentgenogram of pelvis and both hips at time of original injury in January 1943. The film was interpreted as negative. B. Anteroposterior roentgenogram of same pelvis and hips on arrival of patient at Woodrow Wilson General Hospital, Staunton, Va., in early June 1943. Posterior and upward dislocation of both hips is now obvious. C. Anteroposterior roentgenogram of same pelvis and hips 2 years later, after open reduction of right hip had resulted in ankylosis and avascular necrosis. A subtrochanteric osteotomy has been performed on the left. D. Anteroposterior roentgenogram of pelvis and hips after Vitallium cup arthroplasty on right hip in August 1945. (Barnard, L. B.: Fractures of the Femur, Conservative and Operative, and Dislocations of the Hip. [Unpublished data.])

Comment.—When this injury was observed, only 16 cases of dislocation of the hip with fracture of the shaft of the same femur had been reported in the literature (*10*).

Case 4.—A 22-year-old Army Air Forces pilot was admitted to Woodrow Wilson General Hospital, Staunton, Va., on 6 June 1943 (*8*). He had been injured in the Mediterranean theater in January 1943, in a jeep-truck collision in a blackout. He sustained a frontal fracture of the skull, from which he was unconscious for several days, and he had a transient paralysis of the bladder and rectum and a persistent paralysis of the lower extremities. Roentgenograms of the spine and pelvis revealed no injuries (fig. 153), and the paralysis was attributed to the head injury.

When he arrived at the Zone of Interior hospital, the patient presented an obvious dislocation of both hips, with marked upward displacement, and bilateral sciatic

paralysis. An attempt to reduce the femoral heads to acetabular level by Kirschner wires and traction through the lower femur did not succeed. Several weeks later, open reduction of the right hip was carried out, with great difficulty; complete severance of all muscle attachments to the upper third of the femur was necessary. The head of the femur was the site of cartilaginous degenerative changes.

Convalescence was stormy, chiefly because of renal calculi and urinary obstruction. As time passed, avascular necrosis was noted in the head of the reduced femur, and bony ankylosis eventually occurred. In view of the unsatisfactory result on the right side, the similar attack which had been planned on the left side was abandoned, and a subtrochanteric osteotomy was performed, for stabilization. It was well tolerated, and the result was a stable joint, with 35 degrees of flexion, but with 2 inches of shortening.

On 24 August 1945, a Vitallium cup arthroplasty was performed on the right side, and the good movable hip which resulted permitted the patient to sit normally, though some pain persisted. The sciatic paralysis disappeared almost entirely in the right leg, but a partial motor paralysis persisted in the left leg.

Comment.—This case history and the serial roentgenograms attached to it (fig. 153) give a vivid picture of the problem presented by these unrecognized and long untreated dislocated hip joints.

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CHAPTER XXII

Injuries of the Femur

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

GENERAL CONSIDERATIONS

No matter how competent and effective was the management, fractures of the femur were always serious. Even simple fractures sustained in the Zone of Interior represented a serious loss of manpower and gave rise to other problems because of the long periods of hospitalization required, often 4 to 6 months of bed rest, before solid union was attained.

Injuries sustained overseas, associated with compounding, comminution, and infection, gave rise to even more serious problems. Soft tissue damage was often extensive and required attention in the Zone of Interior before bone damage could be assessed and corrected (p. 631). Circulatory damage, however, was not usually a consideration in patients returned from overseas 6 weeks or more after injury. In these circumstances, the circulation was sufficient for nutrition of the extremity, and amputation for this reason was almost never required in the Zone of Interior. It was the policy to hold these casualties overseas until some callus was evident by roentgenograms. In the European theater, they were held up to 120 days except during the Battle of the Bulge, in the winter of 1944–45, when it was expected that the hospitals in the United Kingdom would be needed for the large numbers of wounded. Some patients sent to the Zone of Interior for this reason before the maximum holding period, arrived with displacements in their plaster spicas.

A great deal of indoctrination was required to persuade newly inducted medical officers that plaster casts did not represent the optimum in treatment for fractures of the femur and that traction not only was required by regulations but was also highly efficient. Deformities and shortening were frequent in femoral fractures managed in plaster, and traction, preferably skeletal, resulted in far fewer such complications.

Plaster was the preferred mode of transportation for casualties with fractures of the femur, but it enhanced the loss of knee flexion, which was a major hazard in all femoral fractures. Assisted exercises were instituted as soon as enough soft callus had formed to make them feasible, in order to protect and restore knee function and prevent contractures and adhesions. If the knee was already frozen when the patient was received, the extensive physical therapy necessary to loosen it often had to be deferred because union was not solid and the non-weight-bearing caliper which made

walking possible did not permit flexion of the knee. In spite of intensive therapy and correct orthopedic treatment, knee flexion was often so severely limited in fractures of the femur that separation from service on Certificate of Disability for Discharge was the best way out of the dilemma.

Section I. Noncombat Injuries

TRAINING INJURIES

Neck of Femur

Fractures of the femoral neck, which were infrequent in training, were of two types (*1*):

1. Impacted abduction or undisplaced fractures, which constituted a distinct entity. There was *no shortening*, and the patient could walk without severe pain and without assistance. Both anteroposterior and lateral roentgenograms indicated that the forces that were operative were of the pressure, not the shearing, type. The fracture line was always subcapital and almost always horizontal. The deformity was always of the coxa vara type.

Impacted fractures of the femoral neck did not require reduction or fixation. Traction was never used unless they were the result of gunshot wounds complicated by fractures of the femoral shaft. The reasoning was that the forces resulting from it might actually inhibit osteogenesis. Early, partial weight-bearing, with crutches, was the preferred method of treatment, with the idea that the pressure forces resulting from ambulation would stimulate callus and bone production.

Bony union with this method of treatment was the rule, and the only really serious complication, which was not common, was avascular necrosis of the femoral head. It was managed usually by sequestrectomy of the entire head, in the hope that later, after complete tissue healing, reconstructive surgery or fusion might be possible.

2. Nonimpacted or adduction fractures, which were always serious. In this type of fracture, shearing forces predominated, in contrast to the pressure forces operative in impacted fractures.

These adduction fractures required early, accurate manipulative reduction and secure internal fixation with Smith-Petersen's three-flanged cannulated nail; two screws; and Moore's four stainless steel wire nails, or threaded pins. When shearing forces were extreme, the operation of choice might be a McMurray osteotomy immediately below the lower margin of the femoral head, with fixation by a Blount blade plate (*2*). The shaft could then be placed beneath the head, so that pressure forces would favor bony union between the fragments.

Bony union was frequently delayed, but the results could, on the whole, be considered good, in view of the severity of the injury. There was always, however, a permanent disability, shortening of 1 or 2 inches, and alteration of the angle of the neck, for which fusion might be required. If a portion of the neck had to be removed, the resulting deformity was of the coxa vara type.

The ingenious cast caliper for compound fractures of the acetabulum and the head and neck of the femur, developed at O'Reilly General Hospital, Springfield, Mo., is described elsewhere (p. 373).

Intertrochanteric and Subtrochanteric Fractures

Intertrochanteric fractures were surprisingly infrequent in training camps. Only three were observed at Camp Maxey, Tex., over a 3-year period. All were successfully treated by Russell traction.

The infrequency of these fractures was also commented on at the Army Air Forces conferences in 1943 (*3*). Several reports were made on their successful treatment with nail plate fixation, including 39 civilian injuries treated in this manner. Colonel Shands recommended that this method be used routinely, with the Neufeld blade type of plate, if possible, on the ground that the anatomic and functional results were more satisfactory than those achieved by nonsurgical methods and that less time was lost from duty.

A subtrochanteric fracture of the femoral shaft was the single injury that presented constant and typical displacement of the fragments. The proximal fragment was flexed, externally rotated, and abducted by the iliopsoas and gluteal muscles. If the fragment was abducted, the possibility of an associated posterior dislocation of the hip joint also had to be considered.

Some surgeons considered subtrochanteric fractures an indication for open reduction because of the difficulty of maintaining the proximal fragment in proper alinement. They were in the minority. A variety of methods could be used in the management of these fractures, but the method of choice was skeletal traction with a Kirschner wire through the tibia or lower femur. Knee joint motion and quadriceps function were maintained by active assisted exercises. Elevation of the bed and pressure of the normal foot against a fixed bedboard provided countertraction. Care had to be taken to avoid lateral angulation deformity. The patient usually could be allowed up on crutches after 8 weeks of traction.

Avulsion of the greater and lesser trochanters was uncommon. Treatment was plaster fixation, with the hip so flexed as to approximate the femur to the lesser trochanter and with the thigh so abducted as to bring the femur into accurate apposition with the separated greater trochanter. Surgery was not indicated.

Traumatic separation of the head or capitate epiphysis was an uncommon injury when it was not related to endocrine dysfunction. Avascular necrosis, deformity of the head, and traumatic arthritis were late and serious sequelae. Treatment was immediate, accurate manipulative reduction and secure internal fixation, followed by prolonged immobilization in a hip spica. Open operation, accurate reduction, and secure internal fixation were essential if traumatic separation of the capitate epiphysis was complicated by dislocation of the epiphysis from the socket.

Epiphyseal coxa vara or separation of the upper femoral capitate epiphysis was the result of endocrine dysfunction, usually observed at the

age of 12 or 14 years.[1] It was necessary, however, for medical officers to be able to recognize and treat its sequelae; namely, deformity, avascular necrosis, and traumatic arthritis.

Upper Third of Femur

Simple comminuted fractures of the upper third of the femoral shaft were managed by traction so applied as to restore normal length and maintained sufficiently long for sound union to be effected. All patients were eventually supplied with ischial non-weight-bearing calipers, to protect the fracture line and encourage rehabilitation of the muscle and other soft tissues. Plaster provided excellent mobilization for these fractures, but it did not permit early, active physical therapy (massage, muscle contraction, knee movement), nor did it permit regular examination of the limb to detect early thrombophlebitis or phlebothrombosis.

If fractures were compounded as well as comminuted, infection of the cancellous bone in the region of the greater trochanter was always a possibility to be feared. If it ensued, surgical debridement was often required, sometimes more than once. The operation, while clearly indicated, inevitably left a large deformity and thus increased the ultimate disability. Fortunately, the natural tendency was toward healing.

Old simple fractures associated with shortening were treated with heavy skeletal traction if callus formation was not too extensive. If it was, open reduction was carried out at once. Definitive surgery consisted of lateral bone plating, either alone or with bone grafts.

Middle Third of Femur

The preferred treatment for fractures of the middle third of the femur was balanced suspension skeletal traction in a suspended Thomas or Keller-Blake army splint with Pierson knee flexion attachment. This was the safest method for the average medical officer to institute in an average hospital. It was associated with fewer complications, the period of disability was shorter, and the end results were better than with other techniques. Experiences at the various training camps were all to this effect.

The correct application of this method and the maintenance of the apparatus required an efficient fracture service. Elevating the feet and legs prevented edema. The feet were supported by towels at night. Areas of pressure necrosis over the heel, Achilles tendon, and sacrum were prevented by frequent removal of the causative forces and daily applications of lanolin or some other lubricant to these areas. Rigid shoe supports were not used.

[1] Colonel Shands saw only one such case in his entire wartime experience, in a 19-year-old airman. In 57 cases reported from St. Luke's Hospital, New York, N.Y., in 1951, there were 35 males, with an average age of 13 years and 4 months (4).

They encouraged muscle atrophy, contractures, edema, and circulatory insufficiency. Directed and other exercises were begun immediately after traction was instituted.

The patient remained in bed in suspension until there was roentgenologic evidence of good union between the fragments, which might take 2 or 3 months. Normal alinement was maintained with the aid of bony landmarks and the use of a measure and marking pencil; a red "X" on the skin at the fracture level enabled the technician to center the rays properly. Distraction was avoided. If the result in terms of function was satisfactory, orthopedic surgeons learned to be satisfied with 50-percent contact between the bone ends.

While open reduction might eventually be necessary in some of these fractures, a sufficient period of time—well over 6 weeks—had to be allowed before it was employed. At Camp Swift, Tex., where the results in fractures of the middle third of the femoral shaft were regarded as only fair anatomically but as good functionally, it was necessary to resort to open reduction only twice over a 2-year period (*5*).

Among the suggestions made for the management of these fractures at the 1943 Army Air Forces conferences were (*3*):

1. Skeletal traction to the femur, with adhesive traction to the lower leg. Weight-bearing was allowed in a walking caliper at 4 months, and a caliper was used for a year after injury.
2. Skeletal traction through the head of the tibia, to stretch the muscles of the thigh, which were usually contracted and spastic.
3. Ball-bearing pulleys, to decrease friction and thus increase the efficiency of the traction apparatus.

Lower Third of Femur (Condyles)

Supracondylar fractures were similar to fractures of the shaft of the femur except that the vastus intermedius frequently became fibrosed and adherent to the shaft of the femur so that, even though firm bony union might occur, flexion of the knee was not possible. Resection of the vastus intermedius was recommended for this complication.

Fractures involving the condyles often damaged the interior of the joint. A vertical fracture between the condyles was sometimes associated with a supracondylar fracture; the resulting T-fracture was extremely serious. Whenever routine roentgenograms revealed an incomplete fracture of the femoral condyles, a complete fracture was always to be suspected. It could be demonstrated by repeated roentgenograms, but frequently was not manifest until separation became evident in the course of treatment.

Aspiration of hemarthrosis was the first step in the treatment of supracondylar fractures. Possible techniques of management included manipulative reduction with C-clamp compression and plaster fixation; open reduction with internal fixation by screws or bolts; or some method of

skeletal fixation, which was usually resorted to only after other methods had failed. Skeletal traction was always instituted through the lower fragment, never through the upper end of the tibia. The Griswold technique might also be used, with skeletal traction through the tibia and a canvas support under the distal fragment, to provide anterior traction. When this method was used, the knee was flexed and the extremity supported on a Böhler-Braun splint.

Chip fractures of the articular surface of the condyle were sometimes overlooked. The separated fragments might lead to a diagnosis of osteochondritis dissecans (p. 730). If the loose fragment included a small portion of subchondral bone, diagnosis was less difficult since roentgenologic differentiation was possible. Treatment was surgical removal of the fragment(s).

Section II. Combat-Incurred Injuries

MANAGEMENT OVERSEAS

The following brief outline of overseas management of fractures of the femur is included in this chapter as background for the management of these injuries in the Zone of Interior. For details, the reader is referred to the volumes on orthopedic surgery in the Mediterranean (*6*) and European (*7*) theaters in this historical series.

As related elsewhere (p. 255), closed plaster (Orr-Trueta) management of combat-incurred compound fractures used in the first months of World War II in North Africa proved entirely unsatisfactory. By 1944, it had, for all practical purposes, been written off and had been replaced by a program of reparative surgery instituted in the Mediterranean theater late in 1943 and adopted in the European theater after D-day. In essence, the new plan of management was as follows (*8, 9*):

1. First aid on the battlefield consisted of occlusive dressings; control of hemorrhage; morphine if pain was too severe to be controlled by simpler measures; plasma infusions (blood was not available until a field hospital was reached); the administration of a booster dose of tetanus; local sulfonamide therapy, which was discontinued late in the war; and emergency splinting.

2. Examination in a clearing station determined the location and extent of the orthopedic and other injuries, eliminated local nerve and vascular injuries, and evaluated the casualty's general condition. Depending upon the results of this examination, he was evacuated to an evacuation hospital farther to the rear or was transferred from the clearing station to a nearby field hospital, in which initial wound surgery was performed after resuscitation, with major emphasis on blood transfusions, and roentgenologic studies.

3. The basis of initial wound surgery was adequate debridement, which required good exposure, complete excision of all dead and devitalized tissues and foreign bodies, complete hemostasis, and provision for drainage. The wound was always left open. Even before the war, many orthopedic surgeons were opposed to primary closure of compound fractures, and there is no doubt that the policy of nonclosure had much to do with the low incidence of infection in World War II.

4. The postoperative regimen consisted of standard measures, supplemented by additional blood as indicated. A casualty with injuries limited to the femur, even with injuries of other bones also, was usually transportable to a fixed hospital within 24 to 48 hours after initial wound surgery, with the injured extremity immobilized in a plaster-of-paris spica bandage.

5. The wound was closed in the fixed hospital within 4 to 7 days after initial surgery if it was clinically clean, though a maximum of 10 days was still within permissible limits. Closure of infected wounds had to be delayed until the infection was under control. Drainage was provided in most cases.

6. Definitive management of the fracture was undertaken for the first time in the fixed hospital. Internal fixation, which had a certain degree of popularity through 1944 in the Mediterranean theater, was seldom used in the European theater (p. 377). Balanced suspension skeletal traction was the authorized mode of treatment for fractures of the femur and was maintained until sufficient union had been obtained to permit safe transportation in a plaster spica to the Zone of Interior; this usually required 10 to 12 weeks. This method promoted maintenance of joint and muscle function and prevented angulation and overriding deformity. Care had to be taken to avoid overpull and resulting distraction, particularly when the thigh muscles were divided or otherwise seriously injured; in some such cases, traction had to be delayed until firm fibrous union of the muscles had been accomplished by suture.

7. Transportation of casualties with gunshot fractures of the femur from forward to evacuation hospitals was carried out in the Thomas half-ring splint, applied with the litter bar, ankle strap, and five triangular bandages. If it was necessary to remove the shoe, skin traction was substituted for the ankle strap or hitch around the ankle. Evacuation from forward to fixed hospitals was in a plaster spica or in the army half-ring Thomas splint with skin or skeletal traction. If plaster was used, the cast was well padded and was split through all its layers down to the skin. The omission of the latter precaution could cause such serious consequences that some medical officers recommended court-martial for the surgeons who omitted it. The Tobruk splint, which could be used only in fractures of the lower third of the femur, was permitted for transportation over short distances; it was less comfortable than a spica. In fact, the simplest, most convenient, and most effective transportation splinting was in a low-waisted one-and-one-half double plaster spica, with the knee slightly flexed and with minimal abduction of the hip.

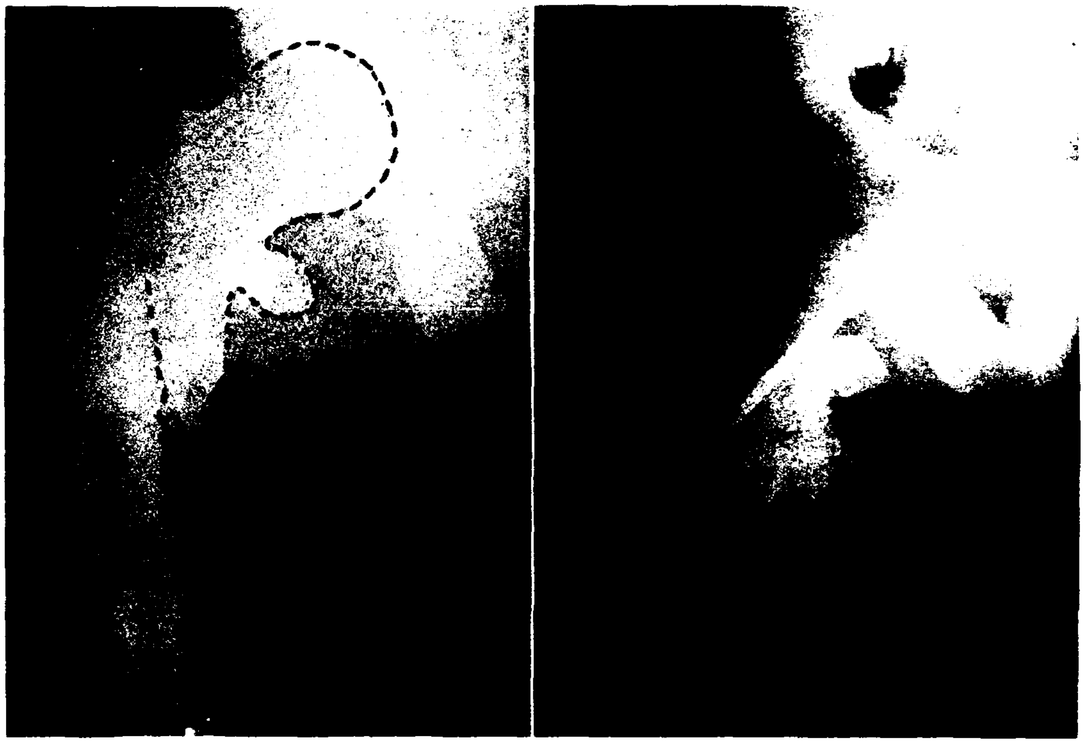

FIGURE 154.—Shortening in combat-incurred compound fractures of right femur caused by too short duration of traction before transportation splinting. (Left) Anteroposterior roentgenogram of right hip and upper femur taken through plaster. Traction had been used for only 5 weeks. At 10 weeks after injury, the fracture was solidly united with 2½-inch shortening and lateral rotation. (Right) Anteroposterior roentgenogram of same hip and femur showing correction of deformity and of shortening after subtrochanteric osteotomy and fixation of fragments with blade plate and screws. (Barnard, L. B.: Fractures of the Femur, Conservative and Operative, and Dislocations of the Hip. [Unpublished data.])

Transportation splinting was not designed to provide anatomic reduction or prolonged immobilization, but simply to move the patient from hospital to hospital. The final move, from the overseas general hospital to a hospital in the Zone of Interior, was not undertaken, as already emphasized, until some degree of callus had formed (*10*). Otherwise, shortening (figs. 154 and 155) and angulation could occur during transit and extensive surgery would be necessary to correct the malunion.

Long before the war ended, experience had made it thoroughly evident that, both overseas and in the Zone of Interior, thorough debridement, delayed primary wound closure, accurate reduction, and complete immobilization were the immutable principles of sound management of fractures of the femur.

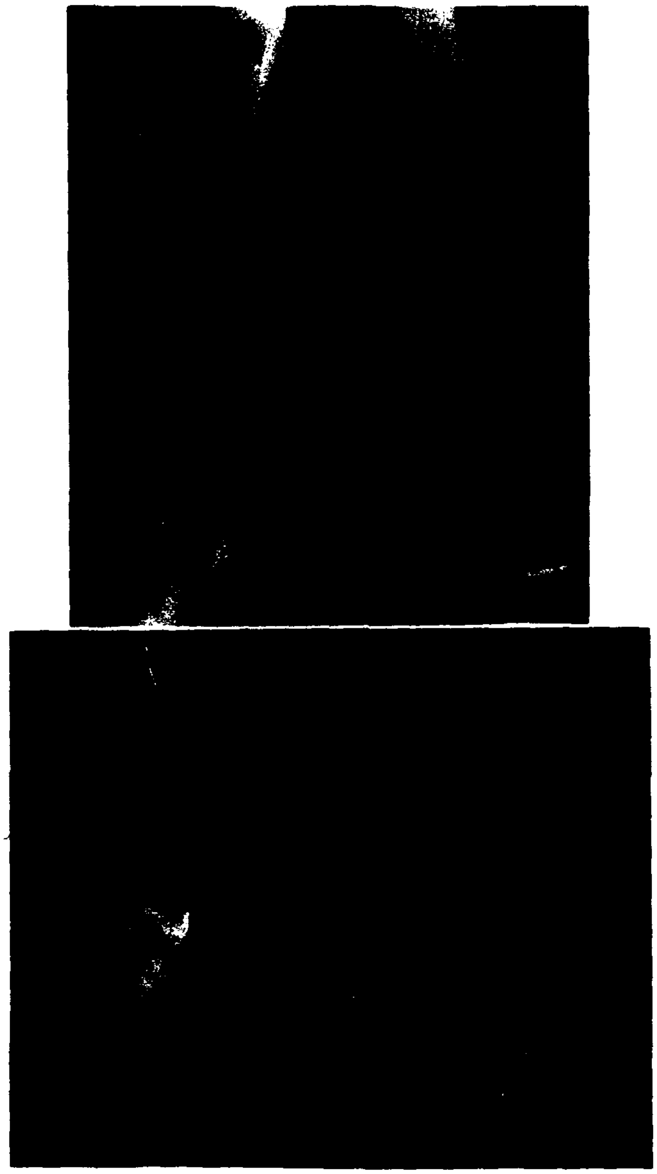

FIGURE 155.—Poor end result in combat-incurred comminuted compound fracture of right femur. (Top) Lateral and anteroposterior roentgenograms of right femur obscured by metal of Thomas splint. There is obvious comminution and loss of substance in the supracondylar bone. A Steinmann's pin is seen in the distal femoral fragment. (Bottom) Lateral and anteroposterior roentgenograms of same femur 15 months after injury. The fracture is united with 2½-inch shortening and knee function is very poor. (Barnard, L. B.: Fractures of the Femur, Conservative and Operative, and Dislocations of the Hip. [Unpublished data.])

STATUS OF CASUALTIES ON ARRIVAL IN ZONE OF INTERIOR

Not many casualties with simple fractures of the femur were returned from overseas in comparison with the number of such fractures, chiefly training injuries, handled in the Zone of Interior. The great majority of casualties from overseas with injuries of the femur had combat-incurred severely compounded, comminuted injuries, sometimes associated with non-union, malunion, poor alinement, a considerable loss of bone, and often also a considerable loss of soft tissue. A small number had associated vascular injuries, though the most urgent of these injuries had necessarily been cared for overseas. A larger number had associated nerve injuries, chiefly injuries of the sciatic nerve. Many had serious wounds of the bladder and intestine related to the femoral injury, as well as injuries in other parts of the body.

Even when patients had been correctly treated overseas and correctly immobilized for transportation, difficulties arose. If the spica was applied when a great volume of swelling was present in the thigh muscles, the local situation, because of muscle atrophy and absorption of hematoma, changed as the volume decreased. As the cast loosened, immobilization was lost, angulation and overriding of fragments became a distinct possibility, and by the time the patient reached the Zone of Interior hospital, callus might prevent correction by traction or other nonsurgical methods. The surgeon would then be forced to decide whether to accept a poor anatomic result or to refracture the bone.

It should be emphasized again, however, as it has been elsewhere (p. 281), that the group of casualties received in poor condition because of their orthopedic injuries was relatively very small. Once the program of reparative surgery was instituted overseas and the closed plaster program had been discarded, the majority of casualties were received with wounds that had been closed by delayed primary suture overseas, sometimes supplemented with split-thickness skin grafts, and that were clean and well healed.

IMMEDIATE MANAGEMENT IN ZONE OF INTERIOR

General Measures

The immediate management of casualties on their arrival in the Zone of Interior depended upon their individual status. When the closed plaster technique was in vogue overseas, the cast was removed at once, the wound dressed, and another cast applied. If overriding or displacement was present, an attempt was made to reduce the fracture and correct the deformity before the extremity was again immobilized. The wound was

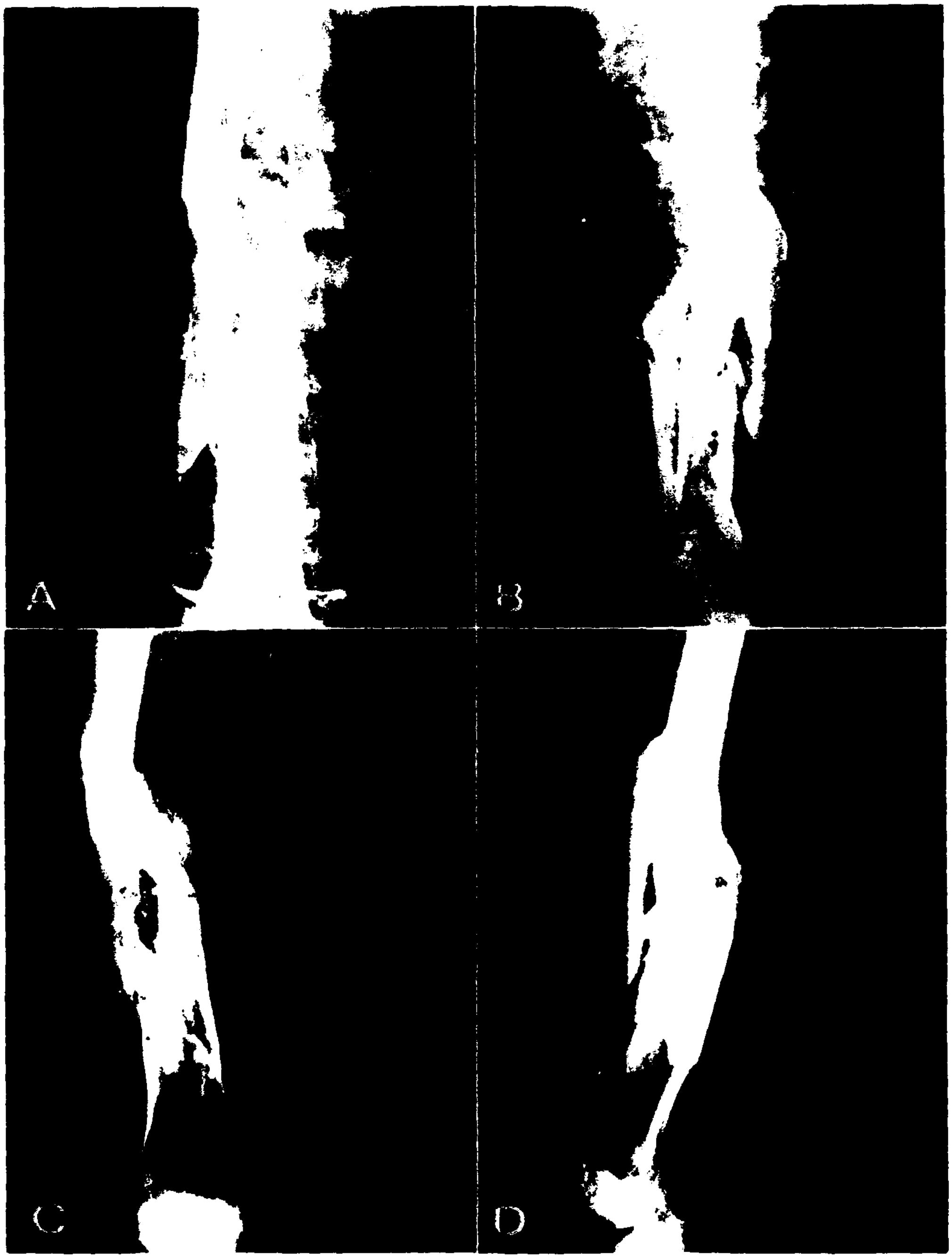

FIGURE 156.—Debridement-delayed closure-skeletal-traction management of combat-incurred compound comminuted fracture of left femur. (Top) Anteroposterior and lateral roentgenograms of left femur taken on admission of patient to Winter General Hospital, Topeka, Kans., on 2 March 1945, 2 months after injury. The wound had been treated overseas as indicated. (Bottom) Anteroposterior and lateral roentgenograms of same femur dated 11 September 1945, almost 6 months after admission. The comminuted fracture has united with only slight deformity of the femoral shaft. The wound remained healed throughout the hospital stay. (Barron, L. J.: Analysis of 220 Fractures of the Femur Resulting From Combat. [Unpublished data.])

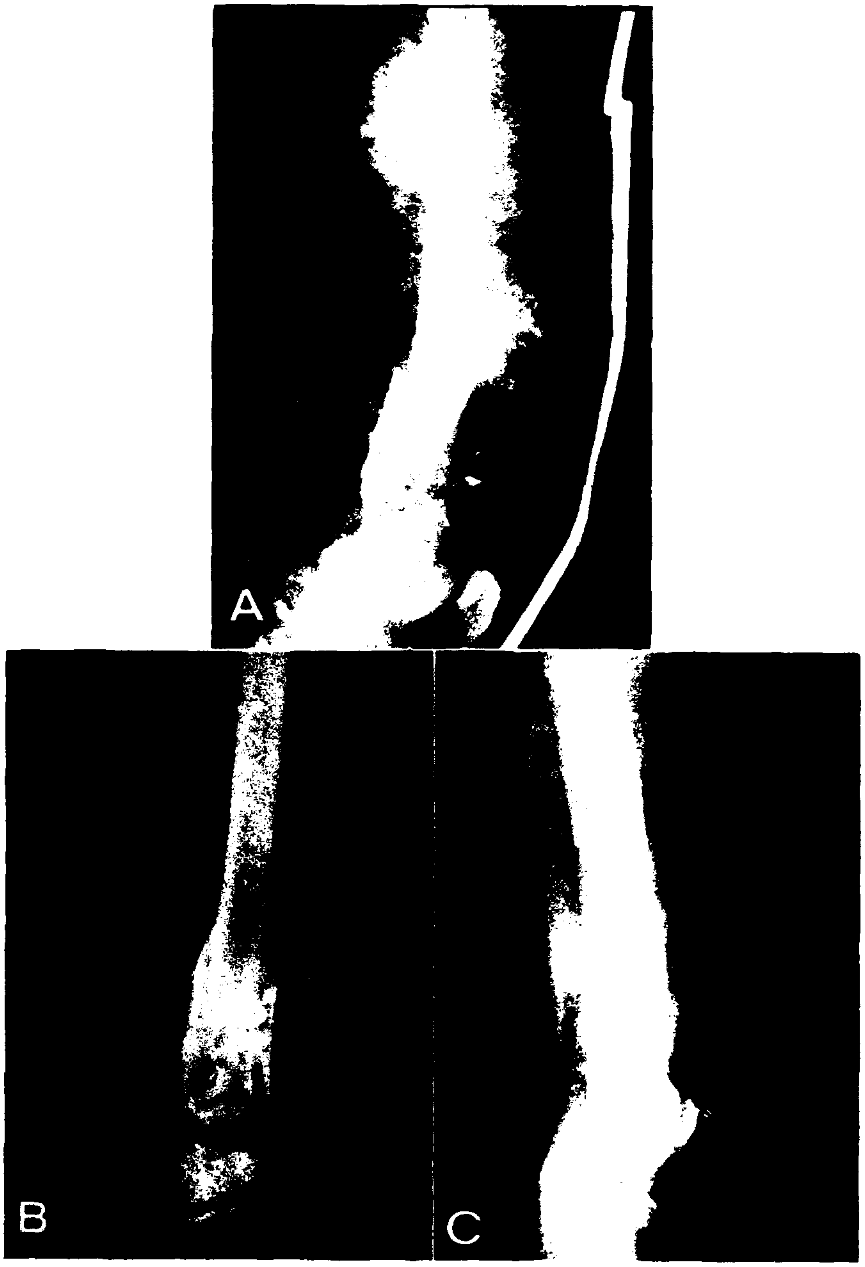

FIGURE 157.—Combat-incurred comminuted fracture of right femur managed overseas without delayed wound closure. A. Lateral roentgenogram of right femur, taken through plaster, showing comminuted fracture of lower third of right femur extending into supracondylar region. Note metallic fragments in situ. The wound was treated overseas by debridement and application of a plaster spica. Delayed closure of the wound was not attempted. B and C. Anteroposterior and lateral roentgenograms of same femur. The fracture has healed, but there is now a draining sinus at the lower lateral aspect of the right thigh. Sequestra are seen in both views.

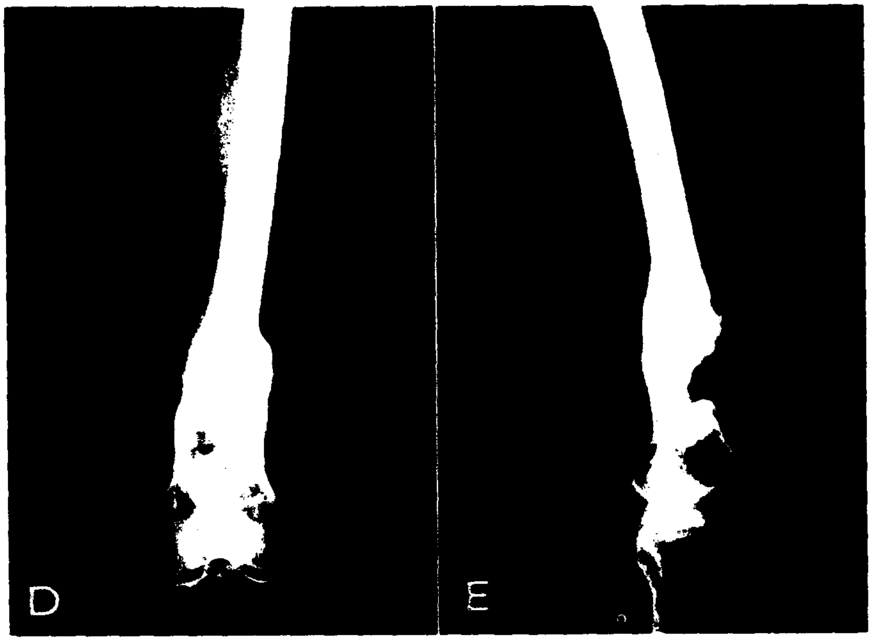

FIGURE 157.—Continued. D and E. Anteroposterior and lateral roentgenograms of same femur in September 1945, after sequestrectomy performed at Winter General Hospital, Topeka, Kans., in June 1945. The fracture is now firmly united and the wound is healed. The active range of motion in the right knee is from 135 to 170 degrees. (Barron, L. J.: Analysis of 220 Fractures of the Femur Resulting From Combat. [Unpublished data.])

irrigated and repacked at intervals, to prevent soiling and reinfection while healing was occurring by granulation. Sequestrectomy was performed as necessary.

Local sulfonamide therapy was used during the period the closed plaster technique was used. By the time penicillin became available, this method of administration had chiefly been discontinued.

After the reparative surgery program was instituted overseas, and the majority of patients began to be received with their wounds closed and healed, or on the way to healing, the transportation cast was removed on their arrival and roentgenographic studies were carried out (figs. 156 and 157). If clinical stability was too uncertain for the extremity to be removed from the cast, the cast was bivalved and the examination made with the posterior shell in situ. It was always desirable, though not always practical, for the orthopedic surgeon or the ward officer to be present and to supervise the position of the limb while the roentgenograms were being made.

Surgical Measures

No matter how well the patient had been handled initially, compli-

cating wounds often required priority attention to close colostomies and cystostomies and to clear up the infections and sinuses associated with these conditions.

In the management of soft-tissue defects, the important objective was not so much early or complete skin closure as coverage of bones, nerves, and tendons, which are normally protected by the apposition of adjacent soft parts and which are highly susceptible to infection (*11*). Transversely divided muscle groups were repaired by suture, and fascial compartments were restored, both to minimize scarring and to improve muscle function. In severely comminuted fractures, when the soft parts were apposed over exposed bone, provision for dependent drainage was a wise precaution. Fascial plane incisions and separation of muscle bundles with fine mesh gauze to expose the fracture site proved superior to drainage by stab wounds or rubber tissue. A posterolateral incision in the thigh, between the vastus lateralis and the biceps, was another efficient method of providing drainage.

The procedures just described, which could be staged if necessary, removed large amounts of scar tissue and greatly improved muscle tone and function. They were required in only a limited number of cases after the program of reparative surgery was instituted overseas and patients began to be received in such good condition that reconstructive surgery on the bones could be undertaken promptly.

PREOPERATIVE PREPARATION

Preoperative preparation, as well as general care on special indications, included transfusion, a high protein diet, and the institution of chemotherapy with sulfonamides early in the war and penicillin when it became available later (p. 451). Casualties with fractures of the femur required surprisingly large amounts of blood in Zone of Interior hospitals, in spite of the large amounts they had received overseas. In some instances, as much as 2,000 cubic centimeters was necessary before surgery could be undertaken (*11*).

TECHNIQUES OF FRACTURE MANAGEMENT

External Fixation

Early in the war, many simple as well as many compound fractures of the shaft of the femur were treated by Haynes, Stader, Steinmann, or Roger Anderson pins. The results were universally poor, and by 1944, these techniques had been completely abandoned and the various splints used in them had been withdrawn from Army hospitals. The unsatisfactory results

reported with these methods at the 1943 Army Air Forces conferences (*3*) led to the decision that, if these forms of fixation were indicated at all, it was only in special cases, with severely comminuted or compound fractures, when reduction by other means was impossible. External fixation should never have been used except by medical officers well trained in the technique.

Infection, with later osteomyelitis, was frequent about pins that broke or broke loose. Sclerosis across the medullary canal also tended to develop at each point of insertion, and the medullary circulation essential for bone repair was thus inhibited.

Internal Fixation

The technique of internal fixation of fractures of the femur is discussed in detail under that heading (p. 635).

Balanced Suspension Skeletal Traction

General considerations.—There were two problems in all fractures of the femur, (1) the fracture itself and (2) the damage that could be caused in the knee joint during the period of immobilization (*10*). Balanced suspension skeletal traction was an efficient mode of treatment, but it was necessary to understand the mechanical and physiologic principles upon which it was based.

Every well-organized fracture service in a Zone of Interior hospital had on it an officer who was trained in this form of therapy and who had trained assistants. In all large hospitals, patients with fractures of the femur were congregated in the same wards, to simplify their care. Every hour of the day, the officer in charge and his assistants were busy adjusting equipment and dealing with the patients, individually and collectively. It was found that explaining the mechanics of their treatment to them was often helpful in stimulating their individual morale as well as the morale of the whole ward.

The maintenance of traction in an Army hospital in wartime was not easy (*12*). Nursing personnel were in woefully short supply. Not all enlisted ward personnel, on whom the burden of maintenance fell, comprehended the rationale and details of this form of therapy or were interested in their work. The majority, however, were interested, and many pieces of equipment and their application were improved by the suggestions they made.

Hospitalization was necessarily prolonged when fractures of the femur were treated in traction. A patient could not be discharged until he had attained maximum improvement, and many casualties, particularly after the war ended, were impatient to get back to civilian life. For their own sakes, as well as in consideration of future disability claims, it was essential

that therapy be continued as long as it was indicated, without regard to other circumstances. One of these other circumstances was the constant pressure on medical officers to turn over their patients and make more beds available. No matter how good the reasons, if traction was discontinued too soon, bowing or angulation at the site of the fracture, as has already been emphasized, was almost inevitable.

There was no doubt at the end of the war that the results accomplished by traction in the treatment of fractures of the femur were far superior, from the standpoint of joints and muscles as well as of bones, than were the result of plaster for definitive treatment (transportation in plaster was, of course, a different matter). With traction, good length and alinement could usually be obtained, and the functional result was satisfactory, even when the anatomic results were not all that might be desired. In the Army, a good functional result was more important than perfect end-to-end roentgenologic apposition of fragments. This policy was in line with Watson-Jones' (*13*) insistence that, in a good result, apposition is relatively unimportant as long as full length and normal bone alinement are maintained.

Attention is also called to the delayed followup studies on fractures of the femur carried out by Dr. (formerly Maj., MC) Joseph D. Godfrey and reported elsewhere in this volume (p. 389). With a wide personal experience in both internal fixation and skeletal traction in the management of these fractures, his unequivocal conclusion was that the treatment of choice for combat-incurred fractures of the femur is balanced suspension skeletal traction.

Technical considerations.—Most patients with fractures of the femur received in Zone of Interior hospitals required traction until the hazards of deformity and shortening had been completely eliminated. The period of immobilization, exclusive of instances of nonunion, varied from as short a time as 6 or 7 weeks to as long as 10 or 12 weeks, or even longer.

Skin traction, because of its simplicity and safety, was used whenever possible, but its field was limited (*14*). Adhesive tape and gauze bandages were frequently used, but a flannel bandage with skin adherent was more comfortable as well as more durable. After the adherent had been applied to the unshaven skin, strips of flannel were cut to the proper length, applied with the flannel side against the skin, and covered with firm, smooth bandages. The success of this method depended upon the care with which the flannel was applied.

Skeletal traction was indicated when skin traction could not be used or would not be effective because of the amount and duration of traction required. In the early stages, traction had to be sufficient to overcome the pull of the strong thigh muscles and to maintain reduction of the fracture. At the same time, it could not be too heavy; if it was, distraction or separation of the fragments would occur. Daily inspection and adjustment were necessary.

Traction could be accomplished in the army leg splint with Pierson attachment or with a Kirschner wire inserted through the supracondylar area of the femur. Most orthopedic surgeons preferred the Kirschner wire to the Steinmann's pin because of its ease of application and the minimum trauma associated with its use. Jointed Steinmann's pins were found to be unsafe and were made obsolete early in the war (p. 385).

The tibial tubercle was the ideal site for insertion of the Kirschner wire in fractures of the lower third of the femur. In this location, away from the knee joint, there was no risk of periarticular thickening or fibrosis of the capsule, and much less risk of the development of osteomyelitis. When the wire was inserted in the supracondylar area of the femur, all of these risks were present, plus the additional risk that the wire would cut through the condyles. Indeed, the only objective of inserting the wire in this area was an attempt to alleviate posterior displacement and hold the condyle in correct position for the weight-bearing line.

Wires were always inserted under rigid aseptic precautions, and preferably in the operating room. They were never inserted in the vicinity of traumatized skin or in the area of a planned operative incision, since even a healed wire tract was a site of potential infection. Nerves, vessels, and joints were carefully avoided. Sufficient bone was engaged to prevent the wire's cutting through and pulling on soft tissues.

The injured extremity was suspended in the splint or hammock after insertion of the wire and was so balanced by weights that movement was possible with the movement of the body while at the same time, the fracture remained effectively immobilized. Rigid fixation of the extremity to the bed or the fracture frame was not desirable.

Supporting slings were smooth and well padded, and rope knots were secure. If a ring splint was used, special attention was given to the position of the ring and the resulting pressure. So far as possible, by positioning of the patient and the bed, the body weight was used for countertraction and minimum weight was applied to hold the splint in position. If the wound was in the ischial region, the half ring of the splint could be reversed to the front of the thigh.

The standard Balkan frame was adjustable and adaptable. It permitted the application of any form of traction on any or all of the extremities in any position desired. A trapeze bar hung on the frame at the correct height, to be used by the patient in pulling himself up, was also indispensable for changing his position in bed and for nursing care.

Active motion was avoided in the early stages of traction, but static muscle contraction, such as quadriceps exercises, was instituted promptly, to prevent atrophy and stiffness as well as to improve the circulation. After partial union had occurred, knee motion was begun, preferably with the use of the Pierson attachment to the army leg splint, which allowed both active and passsive motion of the knee. The sooner knee motion was begun, the better the functional results.

Traction was maintained until all support could be discarded and free recumbent exercises practiced. After clinical and roentgenologic union was evident, bed rest was still required for an additional period of time, as a precaution against refracture. This risk had to be equated against the desirability of as early weight-bearing as possible, to evoke the normal responses to it, to stimulate new bone formation, and to increase muscle tone. Before the patient became ambulatory, he was fitted with a walking caliper, which was removed daily for physical therapy and exercise.

The patient was finally transferred to a convalescent hospital, where graduated activities were continued until maximum hospital benefits had been achieved and he was either returned to duty or, more often, separated from service on a Certificate of Disability for Discharge.

INFECTED COMBAT-INCURRED INJURIES

In infected combat-incurred fractures of the upper or trochanteric area of the femur, the head and neck were involved in most cases, the greater trochanter in a few, and the acetabulum almost without exception. The head was usually completely necrotic and lay free in the acetabulum; it was often greatly fragmented. In some cases, the infection involved the entire innominate bone, extended proximally to involve fully half of the ilium, and extended distally to involve the remainder of the pubis and the ischium.

The Smith-Petersen approach was used whenever it was feasible. Complete excision of the necrotic bone was necessary to control infection and obtain fusion. Excision was, therefore, carried out until viable bone was reached. The neck of the femur, if any of it survived, was placed in the acetabulum. A suspension of sulfanilamide and sulfathiazole was used early in the war. Petrolatum-impregnated gauze was placed in the acetabulum, to be removed on the third postoperative day. The central portion of the incision was left open for drainage. A plaster hip spica was applied. Since arthodesis was expected, the hip was placed in an optimum position for it (15-degree flexion, 10- to 15-degree abduction).

Improvement was usually striking as soon as the source of infection was eliminated. At Walter Reed General Hospital, Washington, D.C., (and at others), the patients' appetites increased, they felt generally better, and they seemed to regain their interest in living. In fact, the chief reason for changing the spicas was their rapid increase in weight after operation.

None of the patients in the Walter Reed series required further surgery, and in three instances, drainage had ceased and the wound was completely closed when the spicas were changed routinely 6 to 8 weeks after operation.

SPECIAL STUDIES

Series 1

The 163 fractures of the femur (117 compound, 46 simple) reported by Lt. Col. Ralph Soto-Hall, MC, and Lt. Col. Thomas Horwitz, MC (*15*), have already been discussed from the standpoint of early internal fixation, which was used in 41 cases (p. 387). Also already discussed is the incidence of infection in this series, which was lowest when debridement was done within 24 hours after wounding.

Technique.—In the 122 fractures in the series treated by traction-suspension, traction was secured by a Kirschner wire or Steinmann's pin

inserted in the distal end of the femur or the proximal end of the tibia, depending upon the level and character of the fracture. As soon as callus was deemed sufficient, transportation to the Zone of Interior was effected in a one-and-one-half plaster spica. Immediately on their arrival, the patients were replaced in traction-suspension splints.

Results.—It is significant that 35 of these 122 combat-incurred femoral fractures (29 percent) healed without infection under this regimen, and 54 (44 percent) healed within 2 to 3 months of the patients' arrival in the Zone of Interior. The mild infections that developed in the latter group were limited chiefly to the soft tissues. The remaining 33 wounds (27 percent) all became infected. They included many instances of extensive loss of bone and soft tissue, as well as vascular damage, and infection in these circumstances was almost unavoidable. There were severe infections in one case in which the sulfonamides were used, four in which penicillin was used, and 16 in which both were used. The figures, analyzed case by case, showed very clearly that the potency of the new drugs did not extend to tissues which had lost their blood supply and in which the antibiotic agent did not make contact with the infection.

Considering the frequency of severe injuries with comminution and bone loss in this series, the number of bone unions, 105 (86 percent), is remarkably high, far higher than the proportion in the fractures treated by internal fixation. Union that did not occur until after 5 months was considered delayed. Both delayed union and nonunion seemed related directly to the degree of bone loss or damage; the presence of infection, particularly severe infection; and distraction, which was extremely harmful even when minimal. Distraction could be avoided by reducing the fracture manually, then using the traction suspension apparatus to maintain the reduction rather than to produce traction.

Complications.—Other complications in the series included the following:

1. Refracture occurred in five cases, on an average of 7½ months from the original injury and 5 to 6 weeks from the beginning of ambulation. The use of a Thomas caliper splint during early convalescence was mandatory at Vaughan General Hospital, Hines, Ill., but these refractures indicate how ineffectual such a precaution is. Indeed, in injuries of the upper half of the femur, this splint may act as a lever and throw the point of greatest stress at the fracture site. Later, on this service, it was the practice to increase the angle of the tilt of the ring, so that its outer portion was above the trochanter. Because of the tendency to angulate and refracture at this high level, it was also the practice, after clinical union was apparent and before ambulation, to require a further period of suspension, with exercises, for 3 or 4 weeks.
2. Renal lithiasis was evident in six patients, usually as they became ambulatory. Had routine roentgenograms been made, no doubt the incidence would have been higher. The explanation was recumbency, gravity stasis, an inadequate fluid intake, and resulting improper renal drainage. Increased calcium output was not a reasonable explanation, since stones never appear in ambulatory patients with fractures of the long bones of the upper extremities.
3. Persistent stiffness of the knee joint was a particularly disheartening complica-

tion in young men of this age group. Statistics do not tell the whole story, since the average period of observation from injury to final examination was only 9½ months, but they do indicate the slowness of restoration of joint function in spite of successful delayed closure, with prompt healing and less scarring and, therefore, an earlier start on exercise and activity. The best results, from this standpoint were achieved in clean simple fractures and the worst in severely infected compound fractures. No difference was noted in fractures treated by skeletal traction in the lower end of the femur or the upper end of the tibia except that the femoral pins or Kirschner wires were not always correctly placed, which suggests that less experienced surgeons would be well advised to use the tibial site.

An important disability in this (and other) series was limitation of extension of 5 to 10 degrees, which was noted in about a third of the cases and was both active and passive. It was explained by treatment of the knee for a long period in a position of flexion, a position which does not allow the vastus medialis to function normally. In this position of prolonged flexion, the intra-articular structures could become temporarily adherent and produce passive restriction. The disability usually could be corrected after several weeks of active exercise, but its occurrence, in the opinion of Colonel Soto-Hall and Colonel Horwitz, argued in favor of treatment of fractures of the femur above the lower third with the knee in full extension, a position contrary to the general usage.

There was no doubt that certain identifiable factors played a part in the loss of joint motion:

A. Matting (adhesions) of the quadriceps at the site of injury, with a resulting checkrein effect.

B. An acute synovitis with effusion, followed by secondary matting (adhesions) of the quadriceps pouches.

C. Traumatic degeneration of the articular cartilage of the patella (chondromalacia).

All of the factors just listed could lead to secondary capsular contraction and intra-articular adhesions.

Physical therapy was carried out by the usual techniques and was supplemented by the weight-lifting exercises devised by Capt. Thomas L. DeLorme, MC (*16, 17*); they were an adaptation of the paraphernalia of professional weight-lifters, consisting of an iron boot with attached bar bells. They were highly effective in improving the muscle power and stability of the knee and also in producing a secondary increase in joint motion. The muscles of the thigh on the injured side were sometimes larger in circumference than those on the intact side. Results were better in cases treated by delayed primary wound closure because these exercises could be undertaken earlier.

Series 2

Essential data.—The following data were obtained by Capt. Leonard J. Barron, MC (*18*), in an analysis of 220 combat-incurred fractures of the femur observed at Winter General Hospital, Topeka, Kans.:

Twenty-two were simple fractures, and 198 compound.

One hundred and seven were on the right side, 113 on the left, and five bilateral.

Seventeen fractures involved the neck of the femur, 57 the upper third, 62 the

middle third, and 81 the lower third. The condyles were involved in 26 cases. Three patients with mild residual peroneal nerve paralysis were transferred at once to neurosurgical centers.

Debridement was carried out in 192 of the 198 compound fractures, in all but a few instances within 12 hours. The upper limit was 72 hours. In the group of compound fractures, 109 wounds were closed by delayed primary wound closure or skin graft, and 98 of these healed without complications. Of the wounds that were open and draining when the patients were received in the Zone of Interior, 32 healed during hospitalization at Winter General Hospital.

Of 174 patients with compound fractures who were known to have received penicillin, 98 were known to have been given it within 24 hours of wounding, 12 within 48 hours, and 31 between 48 hours and 4 weeks.

Of the 198 compound fractures, 164 were treated in skeletal traction overseas, regardless of how the wounds were treated. Transportation in plaster was possible in 3 to 17 weeks in these cases, with an average of 5 to 7 weeks.

Results.—In the 22 simple fractures in this series, clinical and roentgenologic bony union occurred in 16 within 6 months. One of the fractures with delayed union later went on to union. Both cases of nonunion, one in the middle and the other in the lower third of the shaft, were treated by bone grafting.

In 191 of the 198 compound fractures in which the dates of healing were known, there was evidence of clinical and roentgenologic healing within 6 months in 121. In the remaining cases, there were 58 instances of delayed union, 30 of which went on to later union, and 14 instances of nonunion. In 18 cases of malunion and delayed union, there was sufficient loss of bone substance to explain the difficulties. At the time the report was made, 28 patients with delayed union were still under observation.

Function.—In 10 of 14 simple fractures in the upper third of the femur, the average range of active motion of the knee was 95 degrees. In three injuries of the middle third, the average range was 83 degrees, and one injury of the lower third ended with a range of 45 degrees.

Shortening.—Figures for measured shortening of the extremity in 22 recorded simple fractures were as follows:

In 17 simple fractures, there was no shortening in five of 11 fractures of the upper third and an average shortening of 0.9 inch in the other cases.

In four simple fractures of the middle third, there was no shortening in two and an average shortening of 1.1 inches in the other two.

In two simple fractures of the lower third, the average shortening was 1.13 inches.

Parallel figures for 160 recorded compound fractures were as follows:

In 49 compound fractures of the upper third of the femur (including the neck), there was no shortening in 14 and an average shortening of 0.98 inch in the other 35.

In 43 compound fractures of the middle third, there was no shortening in 13 and an average shortening of 0.73 inch in the other 30.

In 68 compound fractures of the lower third, there was no shortening in 23 and an average shortening of 0.85 inch in the other 45.

No data are available for the other 38 compound fractures.

There was one refracture in the 32 simple fractures in the Winter General Hospital series and eight refractures in the 198 compound fractures.

Calculi were discovered in 67 patients who had renal colic or in whom kidney-ureter-bladder studies were made routinely.

Series 3

Essential data.—Woodrow Wilson General Hospital, Staunton, Va., received its first patients on 6 June 1943 (*19*). Between that date and 10 November 1945, there were 615 admissions for fractures of the femur. When the survey herewith reported ended, only 15 had been returned to duty. The majority of those still under observation, however, had solid bony union, and it was thought that, in most instances, their present muscle and joint limitations would improve with time and use.

About 130 of the 615 patients were transferred to other general hospitals because of complications which required special treatment (neurosurgical, vascular, and plastic) or in an endeavor to place them nearer their homes, in the knowledge that a long period of hospitalization was inevitable and that the chances of return to duty, as just indicated, were poor. About two-thirds of the patients received with fractures of the femur were transferred eventually to convalescent hospitals. The period between bony union and achievement of the Army definition of maximum hospital improvement was usually several months, and the use of general hospital beds in this interim was wasteful in itself and not conducive to the speedy recovery of patients with fractured femurs. Convalescent hospitals proved a valuable addition to orthopedic care, and in the future, more emphasis should be put upon them.

Eight patients in the series were separated from service directly from the hospital on Certificate of Disability for Discharge. The single death in the series, from infectious hepatitis, had no connection with the bony injury.

The average age of the 615 patients was 24 years. The fractures were about equally distributed between the right and left sides except for 10, which were bilateral. This distribution emphasizes again the importance of provision of a universal splint.

Many patients had some degree of shortening, as the result of loss of substance at wounding. Surgery in the Zone of Interior was limited to 24 bone grafts, 19 for nonunion and five for malunion. The small number of operations indicates that most of the patients arrived in satisfactory condition, with good bony union achieved or in progress. In view of the severity of many of the injuries, this was indeed an outstanding achievement.

Detailed analysis of 107 fractures.—The following analysis of data

concerns 107 fractures of the femur, for which records were kept with that purpose in mind:

Of these 107 patients, 82 were received from the European theater, 13 from the Mediterranean theater, and 12 from the Pacific.

Vehicular injuries were responsible for most of the 20 simple fractures. The 87 compound fractures, of various degrees of severity, resulted from high explosive shell fragments (53), bullets, rifles, or machineguns (33), and indirect trauma (one).

The regional distribution was fairly even, 33 fractures in the upper third of the femur, 35 in the middle third, and 39 in the lower third.

Clinical union was achieved on an average of 162 days for all 107 fractures and roentgenologic union on an average of 188 days. The figures for simple fractures were 148 and 172 days, respectively; for compound fractures 167 and 193 days, respectively; and for fractures complicated by osteomyelitis 256 and 292 days, respectively. The rapidity of healing in compound fractures is notable, though healing in the whole series was probably influenced by the youth (the average age was 24 years) and the good general condition of the patients.

From the standpoint of treatment, clinical healing was achieved in 155 days and roentgenologic healing in 183 with skin and skeletal traction, and in 154 days (clinical and roentgenologic) with plaster. In the seven fractures treated by open reduction and internal fixation, an average of 378 days was necessary for clinical union and an average of 386 days for roentgenologic union. One of the patients in this group was hospitalized for 450 days and another for 990 days before roentgenologic union occurred; both had serious infections after open operations.

The patients treated by plaster overseas had less severe injuries than those treated by traction and did not require traction to maintain position and length because their fractures, as a rule, involved the upper and lower ends of the femur.

Anatomic and functional results in relation to treatment are stated in table 12. From the standpoint of joint motion in relation to the level of the fracture:

Results in 33 fractures of the upper third were excellent in 14, good in 14, fair in four, and poor in one. In 35 fractures of the middle third, they were excellent in eight, good in 17, fair in eight, and poor in two. In 39 fractures of the lower third, the results were excellent in seven, good in 16, fair in nine, and poor in seven.

TABLE 12.—*Anatomic and functional results of therapy in 107 compound fractures of the femur*[1]

Form of therapy	Number of cases	Anatomic results				Functional results			
		Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
Traction	73	27	25	15	6	27	36	5	5
Plaster	27	11	9	3	4	9	9	5	4
Open reduction	7	3		2	2	2	1	2	2
Total	107	41	34	20	12	38	46	12	11

[1] Anatomic results: Excellent, normal bony alinement and length. Good, satisfactory bony alinement with moderate malposition and shortening. Fair, moderate malalinement and shortening, not sufficient to require surgical correction. Poor, marked shortening, overriding, angulation of fragments.

Functional results: Excellent, normal gait, good muscle power and joint motion (that is, approaching normal). Good, ability to walk well with good muscle power and joint function but lacking complete range and normal power. Fair, moderate weakness and joint stiffness but ability to move about without special apparatus. Poor, marked weakness and joint stiffness.

The figures just stated are too small to attach significant interpretations to, but they are corroborated by similar figures from other hospitals. They leave no doubt that (1) balanced suspension skeletal management of fractures of the femur gave better results than plaster, even though the more severe injuries were treated in traction, and (2) the farther the injury from the knee joint, the better the functional results.

PHYSICAL THERAPY AND RECONDITIONING

Immediate Postoperative Regimen

Directed exercises of the toes and ankles were begun immediately after operation. Knee joint function was regained by assisted active exercises as soon as soft callus had formed. Reflex inhibition of movement of the quadriceps muscle because of pain was overcome by muscle reeducation. The patient was given a piece of three-ply wood, 20 inches long and 2 inches wide at the distal end, with which, at frequent intervals, he struck his entire thigh with light blows, to produce an erythema.

Ambulation

There were different approaches to ambulation. At Winter General Hospital, as soon as the patient was ready for walking, he was fitted with a long-leg, ischial-seat brace, with stiff knee, and with an attached caliper that fitted into the heel of his shoe. Ankle motion was left free. As soon as possible, crutches were discarded for a cane. When complete union had occurred, the patient was gradually weaned from the use of his brace and encouraged to walk without any support. Meantime, functional return of the extremity had been achieved by a regimen of reconditioning. It was noted that it was particularly difficult to achieve the final 5 to 15 degrees of active extension. The use of a brace at this time, with the knee held in 180-degree extension, enhanced the return to complete extension. A loss of 5 degrees was considered acceptable.

Specimen Program of Reconditioning

The detailed program of reconditioning instituted at the Camp Carson (Colo.) Hospital Center by Lt. Col. Vernon L. Hart, MC (*20*), might well have served as a model for all hospitals. In concept and implementation, it was as follows:

1. The program was based on physiologic principles. There was no place in it for massage, heat, and passive exercises, a situation that required physiotherapists to forget much of their past training. It also required the enthusiastic cooperation of

medical officers, nurses, splint men, and the patients themselves. The attendants' hands never touched the patient. He was taught to treat himself and to carry out himself the functional restoration of his own injured extremity.

2. The concept of the program was the restoration of normal neuromuscular function by challenging the atrophied and dysfunctioning muscles with active, objective, resistive, and non-weight-bearing exercises. Muscle inhibition, incoordination, substitution, and atrophy were eliminated by specific therapeutic measures. With return of muscle function, adhesions and contractures responsible for stiff knees disappeared. The ultimate result was knees that were both mobile and stable.

3. Instruction was both individual and group. The importance of patients' cooperation was explained and demonstrated, as was the role of active exercises in correcting fixed contractures of the toes and equinus deformities of the feet. At the Camp Carson Hospital, the foot support on the Pierson attachment, which prevents active exercise, was not used. When it was needed, support was provided at night by a fracture pillow in front of the foot.

4. The entire group was clearly informed that no patient in it would be measured for a brace until he could extend his knee actively and completely and flex it slightly beyond a right angle. "This announcement * * * not infrequently starts action in certain dull and uncooperative personalities."

5. Individual instruction was carried out as follows:

a. The first lesson, planned for a period in the day when the patient was relaxed and comfortable, was a demonstration of normal anatomy and physiology of the lower extremity, with particular reference to voluntary quadriceps function on the normal and then on the injured side. The quadriceps atrophy (or actual loss of muscle substance) present as the result of injury was pointed out. Each thigh was measured at a designated level, and the measurements were repeated and recorded weekly.

b. The second lesson began with a quick review of the first and went on to resistive exercises with a sandbag over the lower leg. The parts of the normal quadriceps muscle were demonstrated, and the patient was shown that to extend the knee actively and completely was more important functionally than to flex it actively and completely. The suspension apparatus was adjusted as necessary to permit complete extension of the quadriceps. At this lesson, the flexor and hamstring muscles were demonstrated and their rhythmic coordination was explained. Finally, reflex muscle inhibition, as it became evident, was explained, and concentration on the regional muscle effort, without dissipation of the effort to other muscles, was emphasized.

6. Group exercises were encouraged for half an hour every second hour during the day. The exercises were always active, objective, and resistive. They were carried out with rhythm, force, energy, and determination. Their careless and perfunctory performance was not permitted. They were assisted by the mechanical apparatus in situ; as the leg was extended, the Pierson attachment followed because the whole apparatus was in balance.

When this program was carried out in the spirit and with the attention to detail just described, it was the rule that in a matter of weeks, and sometimes even of days, the affected limb began to return to normal, with elimination of muscle weakness and atrophy, adhesions, contractures, deformities, circulatory insufficiency, edema, and the phenomena of muscle inhibition, muscle incoordination, and muscle substitution.

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CHAPTER XXIII

Injuries and Other Lesions of the Knee

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Section I. General Considerations

INDUCTION STANDARDS

As part of the planning authorized under the National Defense Act of 1920 (*1*), a revision of physical standards for mobilization was issued by the War Department on 5 December 1932 as MR (Mobilization Regulations) No. 1–5, "Standards of Physical Examination During Those Mobilizations for Which Selective Service is Planned" (*2*). These standards were identical with Selective Service System standards; even the numbering of paragraphs was the same, to prevent any loss of time should mobilization became necessary.

The December 1932 standards remained in effect until 31 August 1940, when MR 1–5 was reissued as MR–9, "Standards of Physical Examination During Mobilization" (*3*). The date is significant. World War II had broken out in Europe on 1 September 1939. A week after the regulations were issued, the President declared a limited National Emergency. Selective Service was being debated in Congress at the time and became law on 16 September 1940.

In the Army mobilization regulations issued in December 1932 (*2*), registrants were accepted for "special and limited" military service with deformities of the knee (including old fractures and other injuries) which did not interfere with their following useful vocations in civilian life and which would permit them to wear military shoes. This specification was continued in essentially the same form in all regulations issued during the war.

In the December 1932 regulations (*2*), registrants with internal derangement of the knee were accepted for "special and limited" military service without reservations or qualifications. In the 31 August 1940 regulations (*3*), again they were accepted for this type of service with this type of disability of the knee joint "if not severe enough to have prevented him [them] from following a useful vocation in civil life." The same specifications appears in MR 1–9, 15 March 1942 (*4*) and 15 October 1942 (*5*). It was rescinded in the Selective Service System Standards issued on 1 February 1943 (*6*).

In the mobilization regulations dated 19 April 1944 (*7*), registrants with internal derangements of the knee again were accepted for limited service with "(1) History of, providing disability has been mild and infrequent. (2) Operation for, providing a period of 6 months has elapsed since operation with freedom from symptoms."

Army Regulations No. 40–105, 14 October 1942 (*8*), concerned only officers (commissioned and warrant). It specified rejection for candidates with chronic synovitis, floating cartilages, or other internal derangements.

Finally, MR 1–9, Changes No. 4, dated 26 August 1946 (*9*), accepted for general service men with internal derangements of the knee as follows:

> History of a satisfactory surgical correction of dislocated semilunar cartilage or loose body of the knee, provided that 1 year has elapsed since operation without recurrence. The knee ligaments are stable in lateral and anteroposterior directions in comparison with the normal knee; the X-ray is negative for pathology; there is no weakness or atrophy of the thigh musculature in comparison with the normal side; there is full active motion in flexion and extension; and there are no symptoms of internal derangement.

During the war, Selective Service System standards in general followed mobilization regulations.

Up to June 1944, musculoskeletal defects had accounted for the rejection for service of more than 316,000 men (*10*). No breakdown of the figures is available, but there would seem little doubt to knowledgeable orthopedic surgeons that a great many of these rejections were for internal derangements of the knee and that a majority of these derangements were for injuries incurred earlier in life, chiefly in such sports as baseball, basketball, and football.

In the light of the wartime experience, these hypothetical rejections seem fully justified. There are few assignments in an Army during wartime that are compatible with an unstable, painful knee. Men so handicapped probably never should have been inducted. They would not have been, at least in significant numbers, if more attention had been paid in induction centers to the interpretation of positive or suggestive histories of old injuries to the knee and if roentgenograms had been taken routinely in inductees with such histories. In some instances, the men were inducted with full knowledge of their past disability. The responsible civilian examiners and medical officers apparently failed to envisage the potential for time lost from duty when a disabled knee was subjected to the stresses and strains of Army life, a loss that assuredly would be greatly increased if surgery should become necessary.[1]

[1] The present (1965–66) causes for rejection for service in relation to the knee are in substance as follows (*11*):

1. Incomplete extension, flexion less than 90 degrees.
2. Dislocation of a semilunar cartilage [meniscus], or loose or foreign bodies within the knee joint, or a history of surgical correction of these conditions within the last 6 months.
3. A lapse of 6 months or more without recurrence since operation, instability of the knee ligaments in lateral or anteroposterior directions in comparison with the normal knee, abnormalities noted on roentgenograms, significant atrophy or weakness of the thigh musculature in comparison with that of the

INCIDENCE OF INJURIES

This chapter on injuries of the knee is statistically inconclusive. It could scarcely be otherwise. There was a constantly changing census at the various posts at which these injuries were sustained or cared for, and which were chiefly, though by no means entirely, training camps. It was not unusual for a general hospital to receive as many as 10 or 12 patients with knee injuries at one time from one training camp. Units were moved to other posts or were dispatched overseas, and the soldiers who had been injured or operated on went with their outfits before evaluation of results was possible. This was especially likely to happen before the reconditioning program had been introduced, with its graduated scale of evaluation of ability to perform.

Another factor that made evaluation of surgical results difficult was the presence of injuries of other structures in addition to injuries of the menisci. Tears of the cruciate ligaments were not too important. Injuries to other ligaments were extremely important, and poor results caused by them were frequently responsible for statistical condemnation of meniscectomy per se. By strenuous individual efforts, a few complete followup studies were made on small numbers of patients, such as the studies at Fort Jackson, S.C. (p. 104), and one or two others. There is some overlapping of data in these studies, and even the best of them are too limited in time to be of great value beyond the clinical impressions they permit. An occasional observer expressed the opinion that more men who had been operated on remained on duty than was generally thought, but the reverse of this opinion was far more general, and in the few accurate studies made, fewer men remained on duty than had been hoped and expected.

In spite of the lack of definitive statistical data, it may safely be said that injuries of the menisci were frequent in the wartime U.S. Army, both as fresh injuries and as recurrences of injuries existing prior to induction. A previously injured knee was highly susceptible to another injury. Meniscectomy was, therefore, the most frequent operation performed on the knee joint and, as a rule, the most frequent operation performed on all orthopedic services.

A few illustrations of knee injuries collected in the course of the war might also be cited:

A formal study of 1,411 internal derangements of the knee, 1,132 of which were

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normal side, lack of acceptable active motion in flexion or extension, or other symptoms of internal derangement.

4. An authentic history or physical findings of an unstable or internally deranged joint causing disabling pain or seriously limiting function. Verified episodes of buckling or locking of the knee without satisfactory surgical correction.

5. A history of surgery for knee injuries if subsequently there was evidence of more than mild instability of the ligaments in the lateral and anteroposterior directions in comparison with the normal knee, if there was weakness or atrophy of the thigh musculature in comparison with the normal side, or if the individual would require medical treatment with sufficient frequency to interfere with his performance of his military duties.

lesions of the meniscus, was made during the later months of the war from Army Air Forces hospitals by a group of orthopedic surgeons headed by Maj. J. Vernon Luck, MC (*12*). This material is used extensively throughout the remainder of this chapter. For convenience, it is referred to as the Luck series.

Of the 691 patients admitted to the orthopedic service at the Army Air Forces hospital at Orlando, Fla. (School of Applied Tactics) during March and April 1943, 97 had complaints referable to the knee (*13*). In 52 instances, the injuries had been sustained before induction. Of 514 operations performed on the orthopedic services of six Army Air Forces hospitals, 210 (41 percent) were on the knee joint, and 155 of these (74 percent) were for injuries of the menisci. At the 1943 AAF (Army Air Forces) conferences (*14*), it was reported from one station hospital that, in the course of a year, approximately a thousand soldiers had been seen who were disabled by knee injuries, though operations had been kept to the surprisingly low number of 30. A second station hospital reported that, during the previous 6 months, 3,500 hospital stay days had been credited to injuries of the knee and that the average daily census for such injuries was 20. Over the last 18 months, at the same station hospital, more than 100 operations on the knee had been performed. Three station hospitals of comparable size reported, respectively, 61 operations in 10 months, 62 operations in 13 months, and 68 operations in 15 months.

In 641 arthrotomies performed in six station and general hospitals in the Fourth Service Command (*15*), Lt. Col. Ralph Soto-Hall, MC, found that 500 were for injuries of the menisci (*16*). The medial meniscus was involved 441 times and the lateral 49 times, while in 17 instances, both were involved.

The distribution of the injuries in these and other series emphasizes the necessity for complete visualization of the knee joint at every operation for knee injuries. Exploration was incomplete unless the following questions could be answered:

1. Had it been determined positively before operation that the injury was unilateral?
2. Was only the lateral or only the medial meniscus torn, or were both torn?
3. Was the fat pad hemorrhagic, or did it contain calcium deposits?
4. Were there loose bodies in the suprapatellar pouch?
5. Were any of the ligaments (anterior or posterior cruciate, medial or lateral collateral) torn?
6. Were there arthritic changes on the articular surfaces of the femur? The patella?

RESULTS OF THERAPY

Injuries to the knee occurred frequently in civilian life, and the results of surgery, when the damage was limited to the menisci, were generally good. On the surface, the outlook in military surgery seemed equally hopeful. All the injuries were in young men, in vigorous health. There was no obvious reason why these men should not be transformed by a relatively simple operation from useless, or at the best limited-service, soldiers to men available for full duty, including combat duty.

It did not work out that way. In fact, it proved impossible to transfer the civilian experience to military life. Certain facts were not appreciated

at the beginning of the war by orthopedic surgeons new to Army life. One factor, just mentioned, was the stresses and strains to which the newly repaired knees were subjected as soon as the patients returned to duty. They were substantial, even when the limited-service category was still in effect. In most instances, it is not necessary for civilians to pursue physically vigorous occupations immediately and without respite when they are released by their surgeons. An Army patient, returned to duty after operation, had to fit himself at once into Army routine. If his basic training was incomplete, he had to begin it all over again, with its violent exercises, obstacle courses, long marches, heavy packs, and other forms of physical endeavor.

Probably the most frequent reason for failure of surgery for internal derangements of the knee in World War II was the failure of medical officers early in the war to appreciate the difference between the circumstances of civilian life and the circumstances of Army life. They had no realization of what their patients were returning to. The comparison of soldiers returned to combat with football players returned to the game was particularly unrealistic. All too often, operations were performed on soldiers who could not possibly be expected to return to full duty, or even to useful limited service, because their joints were too badly damaged from arthritic changes, relaxation of the ligaments, and the chronicity of their lesions, most of which existed prior to induction.

There were other reasons for poor results in the surgery of knee injuries. The diagnoses were sometimes in error, though usually they were correct. The procedures usually were carried out competently. But too often, early in the war, operations were performed indiscriminately by newly inducted medical officers, who, in some instances, were also knife-happy.

It would have been far better to reclassify perhaps the majority of these patients to limited service or to separate them from service on a CDD (Certificate of Disability for Discharge). In large numbers of cases, one or the other of these procedures eventually was necessary.

PSYCHONEUROTIC CONSIDERATIONS

Evaluation of the patient's mental stability was an important aspect of the diagnostic regimen and of the decision as to therapy (*12*). Many orthopedic surgeons considered this evaluation as essential as evaluation of the local pathologic changes. Some first learned of its importance by the unhappy results of surgery.

The knee joint was found repeatedly to be the focus of psychogenic symptoms representing (1) a perpetuation of symptoms from healed organic lesions, (2) exaggeration of existing organic symptoms, or (3) conversion hysteria without an associated organic lesion at present or in the past. Among the postoperative complications of meniscectomy in 1,132

operations collected from Army Air Forces hospitals (*12*) were 22 instances of hysteria, which in two cases took the form of an acute anxiety state and required the transfer of the patients to the psychiatric section.

Specific psychogenic manifestations observed in relation to suspected lesions of the meniscus in the series just cited were:

1. Giving way of the knee. Only very occasionally did the patient fall and injure himself, and associated objective signs in the muscle and joint were universally lacking.
2. Hysterical fixed extension. The patient sometimes walked with the knee rigidly extended (the so-called ceremonial gait), but at other times, full flexion was possible.
3. Hysterical flexion. The patient's gait, with the knee in partial flexion, resembled the position observed in the hysterically flexed spine of camptocormia.
4. Exaggeration of existing organic symptoms. The situation was confusing when a lesion giving rise to symptoms also was known to be present. It was noted that a long cutaneous scar was likely to cause more psychogenic magnification than a shorter scar. It took experience to decide where, in any given case, the organic aspect of symptoms ended and the psychogenic aspect began. An anxiety or tension state was frequently found to be the origin of the magnified symptoms.

When the knee joint was the focus of neurotic symptoms, it was often noted that, as it was passively flexed, resistance would be encountered after a few degrees and the patient would insist that any further movement was impossible. With firm, steady pressure, however, the knee could be moved, albeit slowly and jerkily, through a normal range of flexion and extension. The observation was in striking contrast to the same maneuver attempted with a knee joint limited in flexion by an organic lesion. When substantial resistance and pain were encountered in the process of passive flexion in such a knee, muscle spasm increased progressively and most of the time the patient could tolerate only a few additional degrees of flexion. These phenomena furnished an excellent point in differential diagnosis.

Undue apprehension before operation had many explanations. One was the surprising number of patients who, before induction, had been warned against surgery on the knee by their friends and, occasionally, by ill-informed physicians. It was sound therapy to let such patients associate with patients who had been operated on successfully, and also a good way to let them see the excellent results with exercise after operation and the poorer results without it.

When the knee was so securely locked that even manipulation to the limit of safety could not release it, the surgeon had no choice but surgery, regardless of the patient's emotional or psychotic state. Otherwise, when mental instability or a frank psychoneurosis was present, the wisest plan was to defer operation until reassurance had become effective or until it was evident that it would not be effective.

Except in extreme cases, most orthopedic surgeons learned to supply their own psychotherapy. It was clearly impossible to throw the total burden on the neuropsychiatric staff. It was highly important that a psychologic history, at least in abbreviated form, be taken whenever symptoms referable to the knee were bizarre and out of proportion to the physi-

cal findings. It was also extremely important that psychogenic symptoms be recognized and treated in their incipiency. Once they were established, the problem was tremendously magnified and cure frequently was impossible.

One other point might be mentioned: It is quite true that in civilian life a slow recovery may be motivated, at least in part, by the expectation of compensation or of a cash settlement. It was equally true that, in the Army, it might be motivated by lack of desire to return to duty or hope of separation from service, but it is doubtful that thoughts of later claims for compensation from the Government played much, if any, part in influencing many of the soldiers in World War II.

POLICY CHANGES

The various considerations just discussed altered the thinking of orthopedic surgeons as the war progressed, and it became the policy to operate for EPTI (existing prior to induction) lesions only on definite criteria: when the patients failed to respond to conservative measures, when locked knees could not be successfully treated by manipulation, when there was roentgenographic evidence of intact ligaments, when no arthritic changes were evident, and when the patient was of special military value and had indicated a special desire to remain in service.

A preoperative diagnosis of arthritis was, in general, a contraindication to surgery. Whenever arthritic changes were present, convalescence was more prolonged and the results were likely to be poorer than had been anticipated.

The surgical aspects of internal derangements of the knee were discussed in detail, with special reference to EPTI lesions, at the conference of consultants held in the Surgeon General's Office in October 1943 (*15*). Col. Rex L. Dively, MC, then Senior Consultant in Orthopedic Surgery, European Theater of Operations, stated that in that theater, surgery on this indication was permitted only when he himself had examined the patient, agreed to the operation, and approved the surgeon who was to perform it. Col. John B. Flick, MC, Consultant in Surgery, Ninth Service Command, had observed such poor results from arthrotomy of the knee that he no longer authorized the operation. The results presented by Col. Mather Cleveland, MC, then Consultant in Orthopedic Surgery, Fourth Service Command, were poor then and were to be worse with a longer period of observation (p. 109). Some surgeons thought the only choices were (1) surgery in line-of-duty-yes cases, in cooperative patients with classical symptoms and confident expectation of return to full duty, or (2) separation from service. No formal decisions were arrived at, but there was no doubt of the consensus, that EPTI internal derangements of the knee should be treated surgically only after much thorough and careful consideration.

If anything, there was a later overrealization of the facts of the matter in some quarters. The Consultant in Orthopedic Surgery, Surgeon General's Office, began to observe undue delays in surgery for injuries of the meniscus in which it was obviously indicated. Apparently, the delays were a reaction to the unwise use of arthrotomy earlier in the war. The long-established principle of meniscectomy for internal derangement, Colonel Peterson said, had unjustly lost stature. In his opinion, when arthritic changes were absent, surgical repair of the ligaments was justified whenever there was expectation of restoring otherwise permanently disabled men to limited duty status.

The results of treatment of internal derangements of the knee joint in World War II would undoubtedly have been improved if the implications of certain fundamental anatomic and physiologic facts concerning them had always been borne in mind:

1. The menisci are avascular except at their peripheries. They have no blood or lymph vessels elsewhere, and they secure their nutrition from diffused synovial fluid, which has no healing properties. When, therefore, longitudinal tears occur in these structures, natural healing can be expected only at the peripheries.

2. The function of the menisci remains unclear. Whether any of the functions postulated for them is correct, or none of them are correct, the joint seems able to function as satisfactorily without these structures as with them. When damage is limited to the menisci, treatment—preferably total excision—is simple and satisfactory. When results are unsatisfactory, again with the reservation that lesions are limited to them, it is usually because treatment has been inadequate or has been delayed so long that permanent pathologic changes have occurred.

3. The situation and outlook are entirely different when the supporting ligaments of the knee are involved. Damage to them is serious, whether it is isolated or associated with damage to the menisci. Indeed, ligamentous injuries are often responsible for symptoms and signs attributed to injuries of the menisci that do not exist. Repair of the ligaments, in spite of the multitude of techniques devised to achieve it, is frequently unsatisfactory.

4. The function of the quadriceps, and particularly of its vastus internus component, is extremely important in injuries of the knee. Weakness in it puts a strain upon all supporting ligaments. The quadriceps, which is selective in its action, is also entirely responsible for the last 15 degrees of extension and for stabilizing the joint in all its positions. Weakness in it is responsible for the syndrome that occurs when the knee gives way under strain. Failure to redevelop quadriceps function after operation was the explanation of many surgical failures in World War II. In many instances, in fact, attention to quadriceps function seemed more rewarding than surgery on the ligaments.

As the Consultant in Orthopedic Surgery, Surgeon General's Office, visited the various hospitals in the Zone of Interior, he had a fertile field for instruction of newly inducted medical officers, often with limited civilian experience and usually with no military experience. His instruction on selection of cases for operation, on incisions and other details of technique, on preoperative training in postoperative exercises, and on the postoperative regimen often profitably began with emphasis on the anatomic and physiologic facts just stated.

CONCLUSIONS

As the foregoing remarks indicate, the medical military experience with internal derangements of the knee joint in World War II was, generally speaking, not a happy one. Excellent results were achieved in a considerable number of properly selected and well-handled cases, but by the end of the war, it was apparent that ligamentous injuries of the knee joint constituted a serious disability; a heavy loss of man-days, whether treatment was conservative or surgical and, in most instances, disposition by reclassification for limited duty or separation from service on a CDD.

By the end of the war, there was also general agreement that the important factors in securing good results were proper selection of patients; exposure at operation ample enough to permit inspection of the entire joint cavity; avoidance of surgical trauma; complete hemostasis; treatment of all coexistent lesions; and vigorous postoperative care, particularly the use of the heavy resistance exercises (p. 472) designed to restore quadriceps function, which were also effective in many cases treated without operation.

When the reduction of the holding period overseas made it impossible to handle internal derangements of the knee in those theaters, patients had to be returned to the Zone of Interior for treatment or disposition. Many of them should not have been sent overseas, and many of them probably should not have been inducted. In any event, it was a risk to pass for combat most men who had undergone surgery on the knee. They were usually advised to protect their knees, which was obviously impossible in combat circumstances. There was also the risk of sustaining second injuries during the blackouts in theaters of combat.

The wartime experience made it clear that new standards should be devised to identify, at induction, all men with abnormal function of the knee joint. Most of them should be rejected for Army service. As the World War II experience proves, what they cost in lost man-days and in the professional time and professional skill expended in their care did not, on balance, equal what they contributed to the wartime effort.

This experience also had much in it of value for peacetime orthopedic surgery. It provided a clearer concept of lesions of the menisci, ligaments, and other structures of the knee joint; of the indications for surgery; of the problems of muscular rehabilitation; and of the psychologic aspects of these injuries.

Section II. Lesions of the Menisci

ETIOLOGY

An occasional bizarre tear of the meniscus proved difficult or even impossible to explain, but for the most part, the etiology of these injuries offered no problems.

Half of the patients, or more, had histories of previous episodes. Some of them had had long periods of conservative treatment when they clearly needed operation. Some had never seen any physician. Some had been treated by osteopaths or chiropractors. A large number of them came from small towns and only occasionally had been treated by qualified orthopedic surgeons.

Perhaps half of all the injuries, whether EPTI or LOD (line of duty), could be explained by sports, including football, basketball, track, and baseball (in this order of frequency in the 1,132 cases collected from Army Air Forces hospitals) (*12*). Most of the remainder were injuries sustained in training. A small number occurred without trauma, in walking, stooping, kneeling, dancing, and, very occasionally, during sleep. While these injuries were observed throughout the Army, they were particularly frequent in training centers, where strenuous programs of sport were part of the training and difficult obstacle courses had to be traversed. Running, jumping, climbing, and crawling were all required. When knee mechanics were poor to begin with, injuries were almost inevitable.

There were three principal causes for poor knee mechanics:

1. Many trainees had never in their lives engaged in such strenuous exercises as they were now required to engage in abruptly. Their muscular and ligamentous structures were entirely unsuited for these activities. A carefully graded program over a long period might have put them in condition for the demands to be made upon them, but there was no time in the war years for conditioning before training.
2. As already stated, the genesis of these injuries was frequently in the past, in high school and college sports. A carefully taken medical history would have revealed evidence of many mild injuries diagnosed as sprains, with no episodes of true locking.
3. Many of these injuries occurred in men who had congenital malconstruction of the knee, including genu varum, genu valgum, genu recurvatum, shortening of one leg, poor alinement, abnormal contours, and other physical defects. In other words, some knees were congenitally weak, and when their owners were subjected to full military duty, they proved unequal to the task.

In the 500 injuries of the meniscus collected by Colonel Soto-Hall from six hospitals in the Fourth Service Command (*16*), the etiology was stated in 220; 109 cases were EPTI, chiefly as the result of sports; and the others were LOD, either primarily or as an exacerbation of a previous quiescent lesion. The average age of these patients was 25.6 years.

PATHOLOGIC PROCESS

In the 500 injuries just mentioned, the medial meniscus was involved 441 times (88 percent) and the lateral 59 times, while both were involved in 17 cases. In the 1,132 operations analyzed by Major Luck and his associates (*12*), the ratio of lateral to medial lesions was 1 : 5.1. The distribution in both series is in accord with the usual experience.

In the Luck series, the lesion was located in the anterior third of the meniscus in 228 cases and in the posterior third in 123. It was of the

bucket-handle type in 607. Transverse tears were present in 64 cases, lateral cysts in 55, and medial cysts in four. In 55 cases, 4.8 percent of the total, no lesion was found at operation.

In Colonel Soto-Hall's series, in the 231 cases in which the lesion was described, it was anterior in 40 cases, posterior in 39, and of the bucket-handle type in 152. In these and other series, the incidence of posterior lesions, both isolated and in association with other tears of the meniscus, supported the contention of some orthopedic surgeons that total excision of the injured meniscus should be routine at operation (*17, 18*).

One wartime development in internal derangements of the knee was the clear proof that injuries of the menisci are progressive and that a series of minor injuries is likely to culminate in a final acute injury that can be precipitated by even very mild trauma. Tear of a healthy meniscus can be accomplished only by strong force, but once an injury has occurred, degeneration frequently ensues, and the resulting impairment of nutrition apparently makes the meniscus readily susceptible to further damage.

Hypermobility of the meniscus was reported as a factor in 101 cases in the Luck series (*12*), and the majority of Army Air Forces surgeons insisted that this was a definite pathologic stage, which could result in longitudinal tears because it permitted interposition of the meniscus between the tibial and femoral condyles. MacAusland (*19*), in 850 injuries of the menisci in civilian practice, considered hypermobility second only to fractures as a cause of internal derangements of the knee. Colonel Cleveland and his staff at Fort Jackson denied its existence, believing, with certain other orthopedic surgeons, that hypermobility was used frequently as a diagnosis at exploratory operations which revealed no true abnormalities. Whatever one's opinion about the instability of the knee might be, there was no doubt that the incidence of lesions of the meniscus was higher in loose-jointed persons than in those with tighter joints.

Associated lesions were often created at the time of the original injury to the meniscus and were particularly frequent in chronic cases. In the Luck series, the following were observed (*12*):

Sixty-six interposed and hyperplastic fat pads (p. 688).
Fifty-nine cysts (p. 636).
Forty-nine ruptures of the cruciate or lateral ligaments (p. 674).
Forty-six instances of degenerative diffuse arthritis (p. 665).
Forty-four cases of localized chondromalacia of the patella and femur (p. 681).
Twenty-seven cases of osteochondritis dissecans (p. 690).
Twenty-five instances of loose bodies of undetermined origin (p. 689).

DIAGNOSIS

History and Symptoms

The diagnosis of injured menisci presented no special problems when a clear-cut history could be obtained of an original injury. The story did not

necessarily include trauma. Often trauma was slight. One man developed his difficulty as he rose from his seat in a theater.

A patient who was seen immediately after the original injury was likely to complain of acute pain over the medial aspect of the joint and inability to extend the knee beyond 150 to 170 degrees. Flexion might be approximately normal. He frequently complained of a sensation of something being wedged in the joint when he tried to extend the leg. If he attempted to walk, it was likely to be on his toes because he could not bear the weight of his body on the extended knee.

Even when the patient was seen promptly, locking had frequently been relieved, spontaneously or with help, which frequently was untrained.

In chronic conditions, the history included repeated episodes of locking when the knee was in certain positions or when certain movements were made; then it would catch and could not be extended fully until, spontaneously or after manipulation, "something gave way." After each episode, there was pain on the medial or lateral aspect of the joint line, depending upon the location of the injury. Some swelling was usually present.

It was important to secure the history in detail, which meant a description of symptoms, a statement of the position of the limb when locking occurred, and a full story of the episode. Patients tended to use the term "locking" very loosely, and it was necessary, before accepting their stories, to be sure that they understood what the term meant and implied.[2]

Locking (blocking) was the most typical symptom of a torn meniscus. It was sometimes the first symptom; it might be a progressive development; it might occur only after swelling had appeared; and, in some instances, it might never occur. It was a progressive development in 270 of the 1,132 meniscectomies in the Luck series, its appearance at once confirming the diagnosis, which had previously been in doubt, in a considerable number of cases.

Since the presence or absence of locking was such a conspicuous part of the history of internal derangements of the knee, the orthopedic surgeons who contributed to the Luck series classified the possible syndromes related to it as follows:

1. Syndromes associated with locking:

a. A history of few or numerous recurrences of locking and unlocking, severe with the first episode but with diminishing synovial reactions in succeeding episodes. This sort of history was often associated with tears of the complete bucket-handle type.

b. Progressive episodes in which locking did not occur with the first episode but did occur eventually, often without trauma and after such simple movements as squatting, kneeling, or turning in bed. In such cases, the initial tear was probably not large enough to permit permanent interposition of the meniscus between the condyles.

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[2] Although the term "locking" is retained in this description, in deference to accepted usage, it should be realized that it is really not correct. Actually, the knee is blocked by the torn meniscus and can accomplish only 150 to 170 degrees of extension instead of the normal 180 degrees. Also, the knee can be flexed, which shows again that it is not really locked.—M. C.

With the passage of time, however, the split lengthened and true locking eventually occurred.

2. Syndromes not associated with locking:

a. A history of numerous episodes of snaps, clicks, catches, "clunches," jerks, or episodes in which the knee "gave way." Each episode was associated with an increase of synovial fluid and a brief period of disability.

b. Recurrent episodes of pain and swelling of the knee associated with anterior tenderness but without true locking, clicks, or other momentary symptoms. The episode was frequently precipitated by excessive activity. Included in this group of injuries were bucket-handle tears in which the handle had been in the intercondylar notch for many weeks or months and the tear was so complete that there was no limitation to extension. Diagnosis in these cases was frequently difficult.

Physical Examination

Physical examination was carried out with the patient recumbent and with both extremities completely uncovered, so that muscle atrophy effusion into the joint, and other abnormalities would be evident in the damaged knee and could be compared with the findings in the opposite knee. In some cases, both knees were affected.

The examination included manipulations through the complete range of motion in each knee. Manipulations in the anteroposterior direction while the knee was flexed 90 degrees demonstrated laxity of the cruciate ligaments. Manipulations in the lateral direction, with the knee fully extended or slightly flexed, demonstrated laxity of the collateral ligaments. Manipulations with the leg in abduction and external rotation, and then in adduction and internal rotation, demonstrated tears of the posterior cartilage.

Special attention was paid to unusual mobility and lack of stability in any direction. The patellofemoral function was tested, and an attempt was made to demonstrate any of the tricks the knee might perform.

In examination of the joint for locking, observations at every step of the procedure were made bilaterally. A limitation of extension of as little as 5 degrees was significant, but was likely to be missed on superficial examination, particularly in patients with physiologic hyperextension. Most tears of the meniscus in which the torn fragment was interposed did not limit extension more than 20 degrees, but occasionally a posterior half split became interposed and inhibited the last 40 to 60 degrees of extension, as the following case shows:

Case 1.—In this case in the Luck series of meniscectomies, the knee suddenly locked and extension beyond 120 degrees was impossible. There was pronounced tenderness at the posteromedial aspect of the joint. Roentgenograms revealed no abnormalities, and manipulations (without anesthesia) were not helpful. This patient had undergone a medial meniscectomy several years previously, through the usual anterior approach. When a second arthrotomy was done, it was found that the posterior half of the medial meniscus, which had been left in situ at the first operation, had split and was responsible for the locking of the joint. It was excised through a second posteromedial incision.

If examination of the knee proved so painful as to be unrewarding, anesthesia was promptly invoked, to eliminate the diagnostic confusion caused by the patient's lack of cooperation and the presence of muscle spasm.[3] Subsequent examination sometimes revealed previously undetected instability of the joint, particularly in muscular patients.

Aspiration of an effusion or hemarthrosis was another helpful measure, of therapeutic as well as diagnostic value. Increased synovial fluid was a constant observation in all acute injuries and was also present, though to a lesser degree, when there was a history of recurrent episodes of locking over a long period of time. When only a small amount of fluid was present, it was more easily palpated at the medial aspect of the joint than in the suprapatellar pouch. When large amounts were present, associated with traumatic synovitis, or when hemorrhage into the joint had occurred, thickening and edema of the synovial membrane were fairly common observations. In one series of 200 injuries reported at the 1943 AAF conferences, aspiration was necessary in 199 (*14*).

The McMurray sign.—The McMurray sign, although not pathognomonic of injury of a meniscus, was a useful diagnostic supplement when it was positive. Reports on its value were conflicting. Some surgeons found it positive in all posterior tears. At Letterman General Hospital, San Francisco, Calif., it was found positive in 15 of 112 tests (*20*). It was positive in 20 percent of a group of surgical cases reported at the 1943 AAF conferences; the assumption in some cases was that the meniscus had been incompletely removed at preceding operations (*14*). At the same conferences, one officer noted that, in another series of 77 surgical cases, the McMurray sign had been negative before operation though posterior tears were found at surgery.

Roentgenographic Examination

Routine roentgenographic examinations were negative in acute injuries of the meniscus and were seldom of positive value no matter at what stage they were carried out. They were, however, indispensable in ruling out such associated conditions as fractures, avulsions, arthritis, para-articular calcifications, loose and foreign bodies, and abnormal mechanics of the patellofemoral joint.

So-called stretch films were also frequently useful. They were taken after various maneuvers by which adjacent surfaces of the tibia and femur were separated, with the aim of creating a moderate vacuum and bringing the soft tissues into clear contrast. To study the medial collateral ligament, the film was taken while the knee was in forced abduction and slight flexion.

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[3] One orthopedic surgeon reported at the 1943 AAF conferences (*14*) that, in his opinion, the most common cause of locked knee in acute knee injuries was flexor muscle spasm, accompanied later by quadriceps paralysis or paresis. I doubt the validity of this theory.—M. C.

To study the anterior cruciate ligament, the knee was flexed 90 degrees and the tibial plateau was forced forward. To study the posterior cruciate ligament, the tibia was forced backward. Films taken by this technique often showed minimal changes of diagnostic value and were useful for later reference. Some hospitals used them routinely.

Pneumoarthrography with gas or air was helpful in an occasional problem case, but the diagnostic value of this method was too slight for its routine use. Also, because of the possible introduction of infection, it increased the risks of subsequent surgery, even when operation was deferred for several weeks.

Differential Diagnosis

The rather general tendency to conclude that all symptoms referable to the knee were the result of damage to the meniscus was responsible, as already intimated, for numerous failures of therapy. The existence of an injury, as well as its type and location, had to be established before any decision concerning treatment was reached. One of the important conclusions arrived at during the war concerning knee injuries was the realization that injuries to the menisci were not usually singular and that the lesions they had sustained might, by mechanical irritation, lead to the injury of other structures within the knee joint.

In the absence of locking, the diagnosis, as already mentioned, was frequently difficult. When the lesion involved the posterior horn of the medial meniscus, a typical history was not obtained, and the lack of localizing symptoms might lead to too impetuous surgery on one hand and too long delayed surgery on the other. Aching pain in the knee joints was sometimes the result of calcification in one meniscus or the other, or in both. It was frequently demonstrable by roentgenograms and was relieved by removal of the involved cartilage (p. 655). In other instances, symptoms might be due to pinching of the torn cruciate ligament between the femur and the tibia or to hypertrophy of the fat pad (p. 688).

The point at which tenderness was elicited was of diagnostic importance. If it was over the medial collateral ligament, the diagnosis of a torn meniscus had to be made cautiously. Most surgeons considered localized tenderness the most specific diagnostic sign. It was present in 86 of the 110 operations for internal derangements of the knee at the station hospital at Camp Claiborne, La. (*21*), followed, in order of frequency, by chronic effusions in 68 cases, pain in 61, locking in 59, and quadriceps atrophy in 32.

If it had not been for the damage likely to be done by repeated episodes of nonlocking symptoms, it might have been logical, whenever the diagnosis was obscure, to wait for an episode of locking. This policy, however, would not have been justified for two reasons, (1) that severe damage to the joint might occur in the interim and (2) that the Army could not tolerate repeated periods of disability in its troops. In nonacute

cases, the knee function and capacity for endurance were often tested in the gymnasium or on the obstacle course, since the true signs of internal derangements were most likely to become evident under stress.

That accuracy of diagnosis was perfectly possible is indicated by the experience at Fort Jackson, for instance, where Colonel Cleveland permitted no surgery on the knee joint unless there was objective evidence of pathologic changes (*22*). Similarly, in the Ninth Service Command, Lt. Col. John J. Loutzenheiser, MC, Consultant in Orthopedic Surgery, required, before surgery was scheduled, a complete preoperative description of the pathologic changes anticipated in the menisci and other structures of the joint.

As the war progressed, surgical exploration of the knee for diagnostic purposes became less and less frequent, as was natural, for the results of this policy were generally poor. Meniscectomy, however, performed on correct indications in cases uncomplicated by other injuries remained one of the most satisfactory of orthopedic operations.

INDICATIONS FOR SURGERY

When a patient was encountered with an acute injury of the knee, with the knee locked, the best plan was immediate hospitalization for observation and differential diagnosis. Treatment consisted of rest in bed, hot applications, and very careful manipulation of the locked knee, under general anesthesia if necessary. Aspiration was also carried out, particularly if there was bleeding into the joint. Extensive effusions, whatever the content, caused tense joints and capsular stretching, and also interfered with the lymphatic return in the subsynovial tissues.

If the knee could not be unlocked with these measures, arthrotomy was necessary, but under no circumstances was it considered until sufficient time had been allowed for rest and hot applications, to relax the muscle spasm.

If the decision was to manage the injury by conservative measures, a compression bandage might be applied, or a posterior splint, or a cylindrical cast extending from the upper thigh to the lower leg and kept in place for 3 or 4 weeks. The use of traction (5 to 7 pounds) below the knee was sometimes helpful. During this period, strict attention to quadriceps exercises was essential. As already mentioned, one reason conservative therapy of internal derangements of the knee improved during the war was the better appreciation of the capacity of the powerful quadriceps apparatus to stabilize the knee; heavy resistance exercises enabled many men to regain good function in the knee without surgical interference (*23*).

If there was not prompt response to conservative measures, or if for other reasons surgery was considered necessary, it was performed promptly, to allow no time for secondary pathologic changes.

Such changes were both frequent and serious, so frequent, in fact, that the belief grew that if there were no changes evident at operation when it had been unduly delayed, they simply had not been looked for.

They originated in mechanical trauma to the cartilage produced by the derangement, possibly by the manipulative methods used to reduce the locked knee, or by ligamentous instability.

In 118 operations performed on 112 patients at the station hospital at Camp Claiborne (*21*), degenerative pathologic changes were observed in the medial condyles as well as the medial meniscus in two-thirds of the cases. Other observers reported changes in the lateral condyle, relaxation of the ligaments, chronic synovial effusions and thickening, and arthritis. Changes in the articular cartilage ranged from fibrillation with erosion and shredding of the margin to actual lipping of the joint. Patients who were operated on with these changes already established were apt to continue to have pain after operation, and their chances of being of any military value were minimal.

The possibility of the changes just described furnished sufficient indication for prompt meniscectomy once the diagnosis was made, preferably after the first episode, even more imperatively after the second, whether or not locking had occurred. With this timing, fewer days were lost from duty than when expectant treatment was continued over a period of time: When the initial results were satisfactory, as they were apt to be in properly selected cases, they were likely to continue satisfactory.

These observations, it should be emphasized, were predicated on fresh injuries confined to the menisci. Associated injury of the cruciate ligaments, as already mentioned, did not greatly alter the success rate, but injury of a collateral ligament, or the presence of associated lesions, as, for instance, chondromalacia of the patella, completely altered the picture and was usually a contraindication to surgery in the service.

Preexistent lesions of the knee joint furnished altogether different problems. Early in the war, it became evident that elective operations to remove menisci that were the site of longstanding lesions and that were often—if not generally—accompanied by lesions of other structures were producing very poor results. They were not fulfilling the laudable objective of qualifying men for full military duty. Moreover, if the operation was not successful, the patient's last state was often worse than his first. The conviction, therefore, spread that, unless the lesion had been incurred in line of duty, or unless the surgeon was thoroughly convinced that the patient could be restored to full military usefulness, or unless the patient was of special military value, he should be reclassified to limited duty, or, better, separated from service on a CDD.

Lesions of the menisci incurred or exaggerated in line of duty warranted special consideration:

1. They were generally severe and required long periods of hospitalization, whether or not they were managed surgically.
2. Once the meniscus was torn, it did not heal, recurrences were frequent, and each recurrence was the occasion for further synovial changes, while repeated trauma could lead to irremediable arthritic changes.

3. If the soldier was returned to duty without surgery, further episodes of disability could occur, often at such inopportune times as in combat.

4. When the knee was permitted to become locked several times before operation, the changes for complete rehabilitation were materially reduced. One reason was that longstanding recurrent dislocations of a torn meniscus led to severe atrophy of the quadriceps, which was extremely difficut to overcome and which, if not corrected, left a weakened knee, susceptible to further injury, even after adequate surgery (*23*).

In the 1,132 meniscectomies performed in AAF hospitals (*12*), 712 patients had lesions incurred in line of duty and 420 had preexistent injuries. In this series, it is known that operation was done 214 times after the first episode and 620 times after two or more episodes. Many of the patients in the second group were operated on early in the war, when it was still believed that rehabilitation in such conditions was possible.

Some patients were encountered who had been operated on before induction and who presented atypical symptoms, which it was a temptation to dismiss without investigation. In all such cases, it was necessary to rule out the presence of a portion of the posterior end of a cartilage overlooked or not removed when the joint was opened previously. Its removal through a short posterolateral incision usually gave prompt relief.

TECHNICAL DETAILS

General Considerations

Operation for injuries of the menisci was often performed under spinal anesthesia. The patient's legs hung over the end of the table, with his knees at right angles to it. The surgeon, seated on a stool at the foot of the table, grasped the affected leg between his own knees. He could thus control traction and rotation as desired, secure exposure of the joint, and eliminate the need for one assistant.

Some surgeons did not use a tourniquet, believing that without it the incidence of postoperative hemarthrosis was lower and recovery more rapid. Some used a tourniquet during the operation, but removed it before the surgical wound was closed. If it was used, it was not tightened until the knee was flexed; some surgeons thought that, if the quadriceps was once firmly gripped with a tourniquet, any flexion of the knee tended to produce stretch damage of this muscle. If it was not used, hemostasis had to be extremely precise; hemorrhage was always less of a problem when the surgeon resisted the temptation to excise the normal folds of a fat pad.

There were 19 instances of tourniquet paralysis in the 1,132 meniscectomies studied by the Army Air Forces (*12*); two in the 500 meniscectomies collected from six hospitals in the Zone of Interior by Colonel Soto-Hall (*16*); and two in the 150 arthrotomies reported by Maj. William F. Stanek, MC (*24*), in all of which a narrow Esmarch bandage was used. All of these paralyses were transient.

Incision

The wide differences of opinion among orthopedic surgeons over partial versus complete meniscectomy are reflected in the variety of incisions used, which included, among others, the medial parapatellar, the short curvilinear, and the single-skin, double-capsular (Bosworth) incision (*25*).

Regardless of the type employed, a satisfactory incision had to meet the following requirements:

1. It must not damage the attachments of the patella.
2. It must permit inspection of the posterior surface of the patella.
3. It must permit inspection of both menisci, though some surgeons were willing to forego this requirement in clear-cut instances of bucket-handle injury.
4. It must be capable of enlargement when diagnosis was doubtful or other problems arose during operation.
5. It must provide a direct approach to the interior of the joint, a requirement which eliminated such techniques as splitting the patella, section of the patellar or quadriceps tendon, and any incision that might injure a collateral ligament.

As the war progressed, the Bosworth double-capsular incision gained in favor because it permitted adequate exploration of the joint, as well as entrance into the posterior capsule, through a single-skin incision. Also, it could be extended upward and allowed for reflection of the patella, which might be necessary when, for instance, chondromalacia of that structure was encountered. Impetus to its use also came from recognition that the incidence of posterior lesions was much higher than had previously been realized, plus the clear necessity for using a technique that would permit soldiers to return to vigorous physical activity and full field duty with as few residual symptoms as possible.

Before the war, Bristow (*26*) had pointed out that, with few exceptions, and those only in a lax type of knee joint, the meniscus could not be removed in toto via the anterior route unless part of, or the entire, medial collateral ligament was cut. He recommended that the meniscus be dissected free in its anterior half and then pulled on; his argument was that, if a posterior lesion existed, the meniscus would be drawn into the intercondylar notch and could be cut off. If the meniscus did not dislocate into the notch, the assumption was that a significant posterior lesion did not exist. A great many orthopedic surgeons declined to accept such reasoning and insisted that many posterior lesions could not be visualized by this technique.

In the considerable discussion of techniques at the AAF conference in October 1943 (*14*), the majority of participants expressed their approval of a short incision for meniscectomy. In the 1,132 meniscectomies performed in AAF hospitals in the Luck series (*12*), a single-capsular incision was used in 667 and a double incision in 465, most of the latter operations being performed later in the war.

Steps of the Procedure

Inspection of the joint, when the capsule and synovial membrane were opened, determined the status of the synovia, the anterior cruciate ligament, the articular surface of the femoral condyles and the patella, the fat pad, and any portion of the opposite meniscus that could be observed. Localized tears or detachments of the posterior horn of the meniscus could not be visualized until excision of the meniscus was almost completed.

A number of orthopedic surgeons excised only the portion of the torn meniscus that had split off. The obvious objection to any technique that left the rim of the meniscus in situ was that it was always associated with the risk of also leaving a tear of the posterior meniscus in situ. In the 112 meniscectomies (81 of which were total excisions) reported from Letterman General Hospital (*20*), there were 22 localized posterior lesions, consisting of 10 bucket-handle tears, five angle tears, six avulsions of the posterior third, and one combined posterior and anterior horn tear. Capt. (later Maj.) Donald B. Slocum, MC, and Capt. (later Maj.) Donald E. Moore, MC, who analyzed these cases, insisted that total excision of the meniscus was mandatory in all localized posterior lesions, in bucket-handle tears of the middle third, in lesions of the posterior third in which a second operation was performed, and in avulsions that were complete except for anterior and posterior attachments.

Those who favored a technique by which the rim of the meniscus was preserved justified their position by several arguments:

1. They accepted the theoretical functions of the meniscus (p. 652) and believed that a knee never functioned quite as well again after total meniscectomy.

2. They believed that, when the rim was preserved, postoperative reaction was reduced, so that earlier use of the joint was possible and the period of muscular degeneration was shortened.

3. They believed that leaving the rim in situ was a logical procedure anatomically. Their reasoning was that each meniscus is attached by its thick peripheral border to the deep aspect of the joint capsule. This thick peripheral border is also attached to the margin of the tibial condyle by short fibrous bands (the coronary ligaments). The peripheral margin of the medial meniscus is firmly adherent to the broad, powerful, tibial collateral ligament. If these anatomic relations were borne in mind and if the rim of the meniscus was preserved, it was possible to incise the meniscus through an area that was relatively avascular and to avoid damage to the adjacent synovial membrane. The meniscus was excised flush with the capsule, no attempt being made to separate the rim from its attachments.

The argument that if symptoms persisted, a second operation could be done to remove the remaining portion of the meniscus was obviously specious.

ASSOCIATED PREOPERATIVE CONDITIONS

Arthritis

Degenerative arthritis in localized form was an accompaniment of many injuries of the meniscus with protracted histories of repeated episodes. At the station hospital at Camp Livingston, La., Maj. (later Lt. Col.) Gene D. Caldwell, MC (*27*), noted such changes in the medial aspect of the meniscus in 69 of 83 meniscectomies. Changes in the articular cartilage were in direct proportion to the duration of the internal derangement and did not seem related to the character of the original trauma. If the original trauma, however, also caused relaxation or rupture of the ligaments with the injury to the meniscus, the arthritic changes apparently occurred more rapidly and were more extensive. Major Caldwell was so impressed by these observations that, when, during arthrotomy, he found an area of degeneration in the femoral articular surface opposite the meniscus, it was his practice to remove the meniscus in toto. No matter how normal it might have appeared in situ, he invariably found a lesion of the posterior third present.

The presence of arthritis was frequently evidenced by such findings as crepitus, marginal osteophytes, narrowing of the articular space, and subchondral osteosclerosis. It was surprising, however, how often advanced arthritic degeneration was found at operation when roentgenograms were negative.

When it could be determined during the diagnostic routine that arthritic changes, even if mild, were associated with damage to the menisci or ligaments, serious reflection was necessary before surgery was undertaken. Operation was warranted, in fact, only if the man was of real military value and was truly desirous of remaining a soldier. The presence of arthritis unexpectedly found at operation did not contraindicate the excision of a damaged meniscus. There was, however, no excuse for excision of an intact meniscus if arthritic symptoms had been interpreted as indicative of a tear of the meniscus.

The case histories of five men with severe arthritis at Camp Crowder, Mo., as related by Major Stanek (*24*), are most instructive, and furnish a warning of the risk of inducting men into service with histories of arthritis. On the other hand, as Major Stanek also noted, it was surprising many times to observe how much useful function could be present in a knee joint with marked irregularities of the joint surfaces. His remarks were based on 150 arthrotomies of the knee.

When pain was severe and function obviously lost, meniscectomy was not the solution. Instead, arthrodesis was carried out, but the patient clearly understood what was involved before it was performed. At some hospitals, it was the custom to fit such patients with a brace and allow them to become familiar with its inconveniences before arthrodesis was undertaken.

Cysts

Cysts of the lateral meniscus were found in about 5 percent of the 641 arthrotomies collected by Colonel Soto-Hall from seven different reports (*16*). The frequency was about 4 to 1 as compared to cysts of the medial meniscus. In the 1,132 meniscectomies collected from AAF hospitals (*12*), there were 55 lateral and four medial cysts. Laterally located cysts were particularly common among paratroopers following forceful abduction of the leg at the time of landing (p. 190).

The explanation of cysts of the menisci was mucoid degeneration, usually the result of direct trauma or indirect compression of the meniscus between the femur and the tibia. The wartime experience cast no light on whether these cysts represented a degenerative or a neoplastic process. Usually, they were multilocular and involved the peripheral portion of the middle third of the meniscus.

The clinical picture was chiefly aching pain, recurrent swelling, or giving way of the knee. There was no history of locking. The swelling was beneath, or just anterior to, the lateral collateral ligament. It could be seen as well as palpated and diagnosis, therefore, presented no difficulties.

Treatment was total excision of the cyst and of the meniscus from which it arose. No other method gave any assurance that the cyst would not recur.

Quadriceps Atrophy

A most important associated condition in injuries of the menisci, already mentioned several times, was atrophy of the quadriceps apparatus, which sometimes developed so rapidly that it seemed impossible that it was entirely caused by disuse. It was frequently well marked on the fifth day after injury and practically always well marked by the 10th.

The atrophy of disuse was also important from another standpoint. In many instances, it had become chronic, as the result of enforced immobilization after previous injuries that had never been treated. Another explanation was the rather general tendency before the war to overestimate the importance of protecting the knee from excessive torsion, which was high on the list of causes of recurrence.

Atrophy was an objective as well as a subjective observation. Measurement of the mid thighs, carried out accurately and recorded consistently, was extremely useful. Tests for quadriceps strength included deep knee bends when they were possible. Manual tests of strength were not accurate in strong, muscular individuals.

Rupture of the quadriceps muscle, if complete, was treated by suture, followed by immobilization for 2 or 3 weeks and by protection against forceful motion for another 10 to 12 weeks.

PREOPERATIVE AND POSTOPERATIVE CARE

Preoperative measures consisted of the standard 48-hour orthopedic preparation and training in the reconditioning exercises, particularly the quadriceps exercises, that would be required after operation.

Prolonged immobilization after operation was neither necessary nor desirable. On some services, none was used. As a rule, the compression bandage applied after operation was removed within 5 or 6 days. After that time, the value of immobilization was questionable. The important consideration after operation was not immobilization but reconditioning exercises, particularly quadriceps setting exercises. There was a sharp decrease in the atrophy of this muscle with the evolution of heavy resistance exercises (*23*), special quadriceps exercises, early ambulation, and the correct management of effusions and hemarthrosis.

Postoperative exercises were of such importance in the outcome of injuries of the knee joint that their criteria and routine warrant description in some detail:

1. The patient should clearly understand his role in these exercises and should be able to perform them correctly before operation.

2. All exercises were by the patient's own volition. Passive massage and electrical stimulation were not the equivalent of activity. Many patients who came under observation with unstable knees had been treated by conventional methods for 3 or 4 months with no benefit at all. Under the active regimen which was then instituted, there was rapid improvement in strength within 2 to 4 weeks, and thigh measurements on the affected side approximated normal as compared with the other thigh.

3. On a properly conducted orthopedic service, quadriceps exercises were begun promptly after operation, and sometimes, in particularly favorable cases, on the day of operation.

4. They were repeated for at least 5 minutes of each daylight hour, or a minimum of 10 times during daylight hours, preferably by sharp commands and, in the beginning, under supervision. They were performed slowly, completely, and rhythmically, with complete relaxation between each contraction. If full extension of the leg was not insisted upon, the last few degrees of active motion would not be restored.

5. The quadriceps muscle was to be in good condition before ambulation was permitted. Ambulation with a weak muscle delayed recovery.

6. The use of crutches and canes was never encouraged and, on some services, was forbidden. In an occasional hospital in which the use of canes was permitted, the patients were given shoes with low, broad heels, and were required to protect their knees for several months after operation. These protective measures were a decided exception to the general policies.

7. Since exercise creates power only when there is progressive resistance against muscle pull, the force exerted by the patient was progressively increased, at first with weights and pulleys and, later, with the weight-resistance exercises introduced by Capt. Thomas L. DeLorme, MC (*23*), and others. A bar, to which weights were attached, was fastened to the patient's shoe, and he was required, while seated, to extend the leg fully and return it to the original flexed position (fig. 158). The weights were increased as the power of the thigh muscles returned. Notable improvement in quadriceps power occurred under this regimen within 6 to 8 weeks.

8. As soon as the strength in both lower extremities had become equal, the patient was advanced to the regular reconditioning program (p. 476). It was found that it

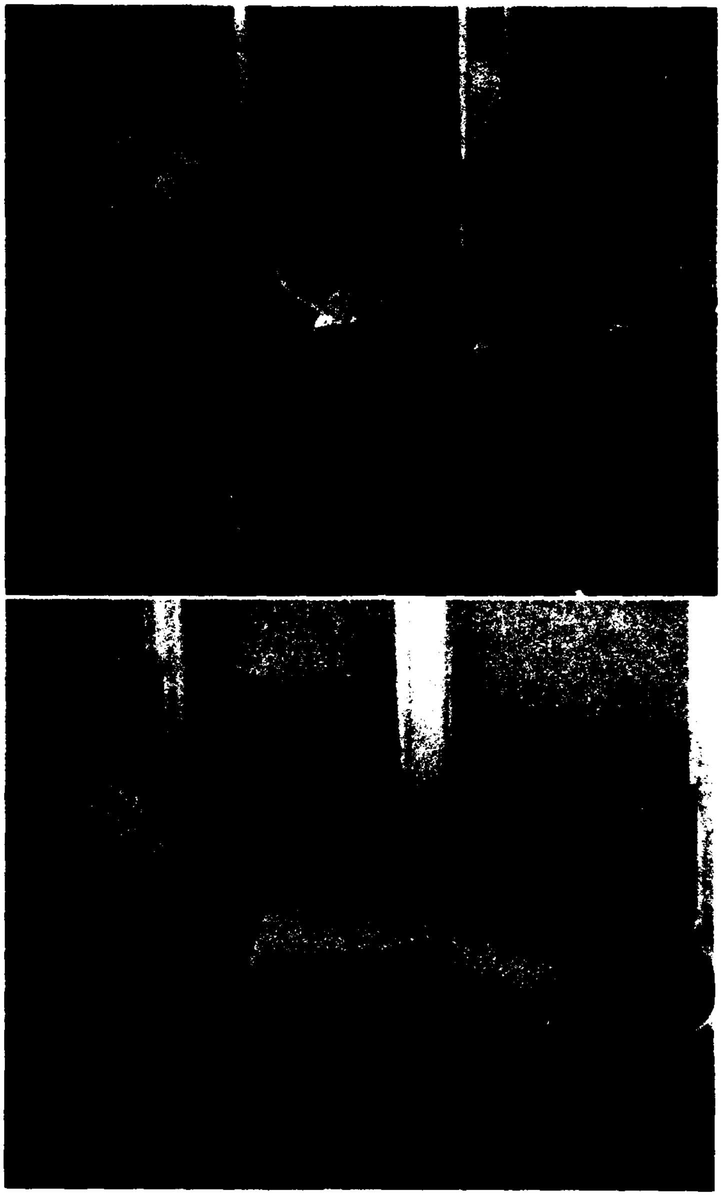

FIGURE 158.—Active heavy resistance exercises to strengthen quadriceps muscle. (Top) Patient seated with bar and weights attached to shoe. (Bottom) Leg extended. It was lifted higher as quadriceps power increased. (West, F. E.: S. Clin. North America 25: 111–135, February 1945.)

paid off in the end to keep him hospitalized 3 or 4 weeks longer than seemed actually required because he was then better qualified to tolerate a full military regimen.

A sensible individualization was, of course, necessary. All exercises had to be used cautiously in the presence of temperature elevations, hemarthrosis, and other untoward developments. As a general rule, the chief

criterion of weight-bearing was the absence of free fluid. If any effusion at all was present, it was likely to increase with ambulation. If patients had been properly individualized, the occurrence of a boggy, weak, relaxed, unstable knee after operation was almost invariably the result of carelessness in respect to postoperative exercises.

POSTOPERATIVE COMPLICATIONS

Ill-advised though many meniscectomies may have been in World War II, the immediate recovery period was singularly unhampered by complications of any consequence. Infection was decidedly uncommon. There was only one instance of infectious arthritis following 150 elective arthrotomies at the station hospital at Camp Crowder (*24*); in this case, there was moderate destruction of the articular surfaces, with partial ankylosis as the final result. In the 500 meniscectomies (*16*) collected by Colonel Soto-Hall (p. 648), there were three infections, and there was only one in the 155 separations from service on CDD which he collected personally. There were six infections in the 1,132 AAF meniscectomies studied by Major Luck and his group (*12*). It should be emphasized that the general policy in these cases was to use the sulfonamides, and penicillin when it became available, only on indications, not routinely.

Other complications in the Luck series were as follows (*12*):

Hemarthrosis, which occurred in 59 cases, was the most frequent of the 114 complications. Whenever it was of significant degree, it was treated by aspiration, which in some instances was necessary several times, in spite of compression bandages. Experience showed that convalescence was decidedly longer when blood was allowed to distend the joint for several days, and it became the practice to employ aspiration both more frequently and more promptly than earlier in the war.

Synovitis developed in 14 cases. As a rule, it was mild and its course was relatively brief, but in a few instances, it was persistent and refractory to treatment. It was thought that other than surgical factors might be responsible in an occasional case in view of the increased sedimentation rate, slightly clouded synovial fluid, and increased local temperature. The most obvious causes were too early weight-bearing and too early and too much knee motion; in a few instances, aviation cadets, eager to return to training, created their own complications in this way.

There was one instance of postoperative pneumonia, three instances of thrombophlebitis, and one of pulmonary embolus, which was associated with thrombophlebitis and in which recovery was stormy.

The 22 cases of hysteria (p. 649) and the nine cases of tourniquet paralysis (p. 662) in this series have already been discussed.

CAUSES OF SURGICAL FAILURE

The principal reasons for failure in meniscectomy were as follows (*28*):

1. Unwise selection of cases. Surgery for EPTI lesions should have

been limited to carefully selected patients, with a favorable mental attitude; no other disability that would preclude full duty; normal collateral and cruciate ligaments; no roentgenologic evidence of joint injuries and arthritic changes; and an almost normal quadriceps apparatus. Extensive weakness or atrophy of this muscle should always have been regarded as a contraindication to operation. If these requirements were not fulfilled, surgery could not be expected to make a man fit for full duty. Nor could the removal of a damaged meniscus restore stability to a knee or make it functionally useful if other pathologic changes existed. By the end of the war, it was generally agreed that surgery for injuries of the menisci was not of sufficient military value to warrant its performance except on special indications.

2. Diffuse degenerative changes in the joint, not seen by roentgenograms; chronic synovitis, exacerbated by strenuous activities; associated conditions, such as chondromalacia of the patella and osteochondritis dissecans; and a psychosomatic overlay.

3. Surgical errors. These included incomplete removal of the meniscus; excision of the wrong (normal) meniscus; and extensive and traumatic surgery. Removal of both menisci from the same knee was undesirable.

4. Inadequate postoperative care, of which the most important factor was disregard of preoperative and postoperative quadriceps exercises.

Many of the results classified as failures in the various series of meniscectomies analyzed in this chapter would have been classified as good in civilian life, in which, as already mentioned, the stresses are different. Very few civilian occupations are associated with the rigors to which the foot soldier is subjected in training, on maneuvers, and in battle. Flying personnel received numerous injuries of the knee in basic training, but few sustained them in flight; most officers and crewmen receiving flying pay who were operated on were able to return to full duty.

SPECIAL STUDIES

Camp Roberts Station Hospital

In his analysis of 155 meniscectomies performed at the station hospital at Camp Roberts, Calif., Maj. (later Lt. Col.) Russell F. Jaekle, MC, found certain features of the material of prognostic importance (*29*):

1. Age was of no significance within the limits, 18 to 42 years, in these patients. Men over 30, however, seemed more stable and worked harder at rehabilitation than younger men. Good results were secured in all the patients in this age group.

2. The time interval between injury and operation was of importance in relation to the man's occupation and the number of recurrences. In this series, it ranged from under 6 months in 72 cases to 11 years in one case.

3. Erosion of the cartilaginous surface of the femoral condyle directly overlying the torn portion of the meniscus was frequently seen in patients operated on several years after injury and with a history of multiple recurrences. The erosion was considered due to the pressure of the dislocated meniscus. It was generally more extensive than roentgenograms suggested. When these changes were present, though it was possible to remedy the mechanical interference with joint motion, it was too late to accomplish a cure by meniscectomy, and nothing could be done for the roughened joint surface and the pain that accompanied it. In a few instances, erosion, which was not always evident on roentgenograms, was seen as early as 2 years after injury. In three cases in this series in which the duration ranged from 9 to 11 years, the joint surfaces were grossly normal and the results of surgery were good.

So many men at Camp Roberts with a history of several recurrences showed moderate to marked erosion of the femoral condyle, as well as arthritic changes, 4 or 5 years after injury that it was concluded that the best plan for anyone doing physical work was surgery shortly after injury, as soon as the acute phase had subsided. Surgery without delay was also recommended in bucket-handle injuries which could not be reduced by manipulation.

4. A vigorous routine of early exercises and early weight-bearing was justified because, in a patient operated on with only an injury of the meniscus, no damage to the joint had been sustained and no functional loss was incurred by removal of the meniscus. The cartilaginous surfaces of the tibia and femur remained intact, and they articulated as before injury. There was, therefore, no contraindication to early ambulation beyond the discomfort caused by the surgical incision.

The genesis of this regimen at Camp Roberts lay in the fact that three patients attached to the Medical Department returned to work, at their own request, between 9 and 11 days after their operations. They had full motion, no soreness or swelling, and no instability of the joint. Later, they were sent overseas, and at the end of 8 months, all of them were known to be on full duty. After this demonstration, the program of early ambulation and exercise to the point of tolerance was pushed vigorously, with excellent results. A comparison of the last 50 consecutive cases in this series with the total series showed a general reduction in the time required for maintenance of splinting and for ambulation, 90-degree flexion, and squatting on the heels. Return-to-duty days were reduced from an average of almost 25 to an average of 21, the time including any additional days required by return to the hospital for further convalescence. This period was considered sufficient for a man to accomplish all the physical exercises required during training.

The followup of these 155 patients covered periods of observation from 6 weeks in two cases to 12 to 28 months in 50 cases. Their status was as follows:

Four had been reclassified and eight had been discharged, four after periods of light to full duty from 3 months to 1 year. In one of these cases, and in three additional cases, psychoneurosis was an important or primary factor.

Six patients complained of soreness in the knees and were given temporary light duty. They had no complaints at six months.

Five complained of soreness for 3 months, but remained on full duty and seemed entirely normal at 6 months.

One hundred and thirty-two had no complaints and no positive physical findings after they went back to duty as combat soldiers. In seven instances, joint changes had been apparent at operation; it was expected that a longer followup would show some eventual disability, but none of the seven had any complaints or presented any additional abnormalities at 6 months.

Fort Jackson Station Hospital

Perhaps the most objectively studied series of arthrotomies put on record in World War II was from the station hospital at Fort Jackson. They were reported, respectively, in April 1944 (*22*) and October 1945 (*30*).

The details of this study are related elsewhere in this volume (p. 104), but the conclusions derived from it are worth repeating here:

> The complete rehabilitation of only 29 of 75 men submitted to arthrotomy of the knee for injuries of the menisci did not warrant the continued use of that operation. Instead, men with definite history of injury of the knee before induction should be reclassified to limited service or separated from service, depending upon the seriousness of the damage. Those with line-of-duty injuries should either be discharged, with the benefit of surgery first if they desired it, or be kept on duty, with surgery performed, if it was indicated, only after careful evaluation, including evaluation of the man's emotional stability.

The Fort Jackson surveys showed very clearly the importance of reconditioning facilities in military hospitals, with provision for gradual resumption of full duties by the patients while they were still under hospital control. The use of these facilities in this series undoubtedly lowered the rate of reclassification and discharge after the men were returned to duty.

OTHER REPORTED SERIES

A curious lack of realism pervades many of the reports of meniscectomy, undoubtedly because the observations were not sufficiently long term. It is highly doubtful, for instance, that the 291 (of 500) men in Colonel Soto-Hall's collected cases (*16*) who returned to full duty remained in that status. The experience at the station hospital at Camp Claiborne is illuminating (*21*). In a report made in 1943, before disenchantment with elective surgery of the knee had set in, there were 96 returns to full duty in 110 meniscectomies. In another report, also in 1943, there were 100 such returns in 104 operations (*27*). In 1945, Major Caldwell, who had made the latter report, doubted that as many as 40 percent of this number had

remained in full-duty status, since many of them had shown at operation extensive and irreversible changes.

Another note of realism was struck by Major Breck, at the regional hospital at Camp Swift, Tex. (*31*). He reported that 75 percent of men with knee injuries returned to full field duty, but a "remarkable" length of time (3 to 4 months) was necessary to rehabilitate them, and postoperative effusions were present longer than had previously been realized.[4]

Section III. Lesions of the Ligaments

SOURCE MATERIAL

The material on which this section is based is derived from the following special studies, in most of which, unfortunately, injuries of the ligaments are not separated from other injuries of the knee joint:

One hundred fifteen cases of knee disabilities requiring CDD at Percy Jones General Hospital, Battle Creek, Mich. (*33*). In 30 of these cases, the injury was primarily ligamentous, and in 25 others, injury of the ligaments was the major pathologic process.

One hundred consecutive arthrotomies at Camp Roberts (*29*).

Seventy-nine arthrotomies at Oliver General Hospital, Augusta, Ga. (*34*).

One hundred fifty arthrotomies at the station hospital at Camp Crowder (*24*). In 13 of these cases, injuries to the menisci were complicated by rupture of the cruciate or collateral ligaments, and in three others, the injuries were limited to the ligaments and fat pads.

One hundred twenty arthrotomies at the station hospital at Fort Benning, Ga. (*35*), in three of which injuries of the cruciate ligaments were combined with injuries to other internal structures.

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[4] What seems to be the most complete followup study of arthrotomy of the knee joint in World War II was put on record by Col. Edwin F. Cave, MC, Maj. Carter R. Rowe, MC, and Capt. (later Maj.) Lester B. K. Yee, MC, from the South Pacific, in October 1945 (*32*). It covered the period from July 1942 to July 1944 and concerned 121 of the 124 operations performed during this time; the other three operations were performed on Australian personnel. Every possible source was investigated to determine whether the patients were still on duty and, if they were, what their status was.

The patients were classified into three groups, (1) uncomplicated injuries limited to the menisci, (2) complicated injuries involving other structures of the knee joint as well as the menisci, and (3) complicated injuries involving structures of the knee joint other than the menisci. There was careful selection of the patients for operation, with complete preoperative evaluation, including neuropsychiatric evaluation, and reconditioning was mandatory before discharge from the hospital.

The conclusions reached by these observers were essentially those reached by orthopedic surgeons in the Zone of Interior:

1. The "vast majority" of patients with uncomplicated injuries of the menisci can be returned to, and will remain on, full military duty after operation if the proper specifications for surgery are met.

2. Patients whose knee disability is caused by, or complicated by, articular damage or instability of the joint should be operated on in an overseas theater only if they experience severe pain and locking of the joint. No exceptions should be made to this policy except for key personnel who, after operation, can return to limited service which does not require excessive strain on the knee.

Careful reading of this instructive report is recommended.

Sixty-five arthrotomies from Vaughan General Hospital, Hines, Ill. (*16*), in 12 of which there were ligamentous injuries.

Thirty-two arthrotomies for injuries of the ligaments in 1,411 internal derangements of the knee in Army Air Forces hospitals (*12*).

Seventy-six arthrotomies from the station hospital at Fort Jackson (*22, 30*).

Eighty-three arthrotomies from the station hospital at the New Orleans, La., Port of Embarkation (*36*).

ETIOLOGY

The etiology of injuries of the ligaments was similar to that of other injuries of the knee joint. Basically, it was the stress and strain of military life, in which, at least in training camps, the strenuous program of organized athletics played an important part. These factors led to fresh, acute injuries and reactivated old injuries which had been overlooked at induction, as was almost inevitable in a system which did not include routine roentgenologic examination of the knee joint. These old injuries were frequent. In the 32 arthrotomies performed for ligamentous injuries in the AAF series (*12*), the duration was a month or less in 18 cases, but was more than a year in 14.

MECHANISM AND DIAGNOSIS

The medial collateral ligament.—Injuries of the medial collateral ligament were more frequent than those of any other ligament of the knee. They were particularly common in football and skiing accidents.

The mechanism of injury was essentially the same as that of injuries of the medial meniscus. That is, flexion, abduction, and lateral rotation of the tibia occurred while the weight was borne on the foot of the affected side and force was directed from the outer aspect of the knee. The superficial and deep fibers of the medial collateral ligament were torn first, after which the anterior cruciate ligament was torn as it was stretched by the medial border of the lateral femoral condyle. Tears of the menisci often occurred in association.

The mechanism just described was frequently observed in cases characterized by lateral slippage of the patella (p. 681), after which continuation of stress could result in serious injury to the supporting ligaments. A check of the status of the medial collateral ligament was always indicated whenever there was even transient displacement of the patella.

Pain ensued over the inner aspect of the knee joint immediately after injury. At first, it was mild enough for the patient to continue with his usual activities, though it was likely to increase in severity within a short time. Inability to extend the leg might not be noticed for 24 hours, in

contrast to the timing in injuries of the meniscus, in which locking usually occurred immediately. Tenderness was elicited over the ligament rather than in the anterior joint line, as in injuries of the meniscus. Moderate to severe synovitis was present, frequently with hemorrhagic fluid.

If the tear was severe, spreading of the joint was noted as soon as the leg was forcibly abducted. This positive abduction sign was of the greatest diagnostic significance. It was easily elicited when the ligament was greatly relaxed, but in questionable cases, pain and spasm often made examination difficult. An injection of Novocain (procaine hydrochloride) over the tender area was useful; with relief of pain, complete extension of the knee might be possible and would aid in differentiating a ligamentous injury from an injury of the meniscus. If there was considerable hemarthrosis, aspiration was useful both diagnostically and therapeutically. If these measures were not successful, examination under anesthesia (Pentothal sodium) was advised.

Palmer (*37*), and Abbott and his associates (*38*), laid much stress on a positive abduction sign which they believed was not present with an intact anterior cruciate ligament when the knee was in complete extension, even when the medial collateral ligament was completely ruptured, though it was present when the knee was slightly flexed. These observers also pointed out that positive abduction rocking with the knee fully extended suggested a tear of the anterior cruciate ligament, as well as of the medial collateral ligament, and was an indication for surgery. Finally, they believed that the drawer sign (increased anteroposterior motion) pointed to an injury of the cruciate ligaments (fig. 159).

Palmer, and Abbott and his group, advised that roentgenograms be taken under anesthesia, with the knees bound together and slightly flexed on a pillow, the feet wedged apart with sandbags, and the cassette under the pillow. Anteroposterior roentgenograms were useful in demonstrating differences in the joint spaces on the medial aspect of the knees. Positive roentgenograms were of great value when the clinical examination was not conclusive.

The lateral collateral ligament.—Complete tears of the lateral collateral ligaments were not so serious as tears of the medial collateral ligament, but when they did occur, the separation often involved the upper end of the fibula, with avulsion of the tip. The mechanism was the reverse of that just described for injuries of the medial collateral ligament: The force was applied from the inner aspect of the knee, with the foot fixed, and the sequence was adduction, internal rotation, and flexion. Tears occurred in the lateral collateral ligament, in the anterior cruciate ligament, often in the tendon of the popliteus muscle, and, occasionally, in the common peroneal nerve, in that order.

Symptoms and signs in injuries of the lateral collateral ligament were the same as for injuries of the medial collateral ligament except that tenderness was elicited over the outer aspect of the joint, most commonly at the

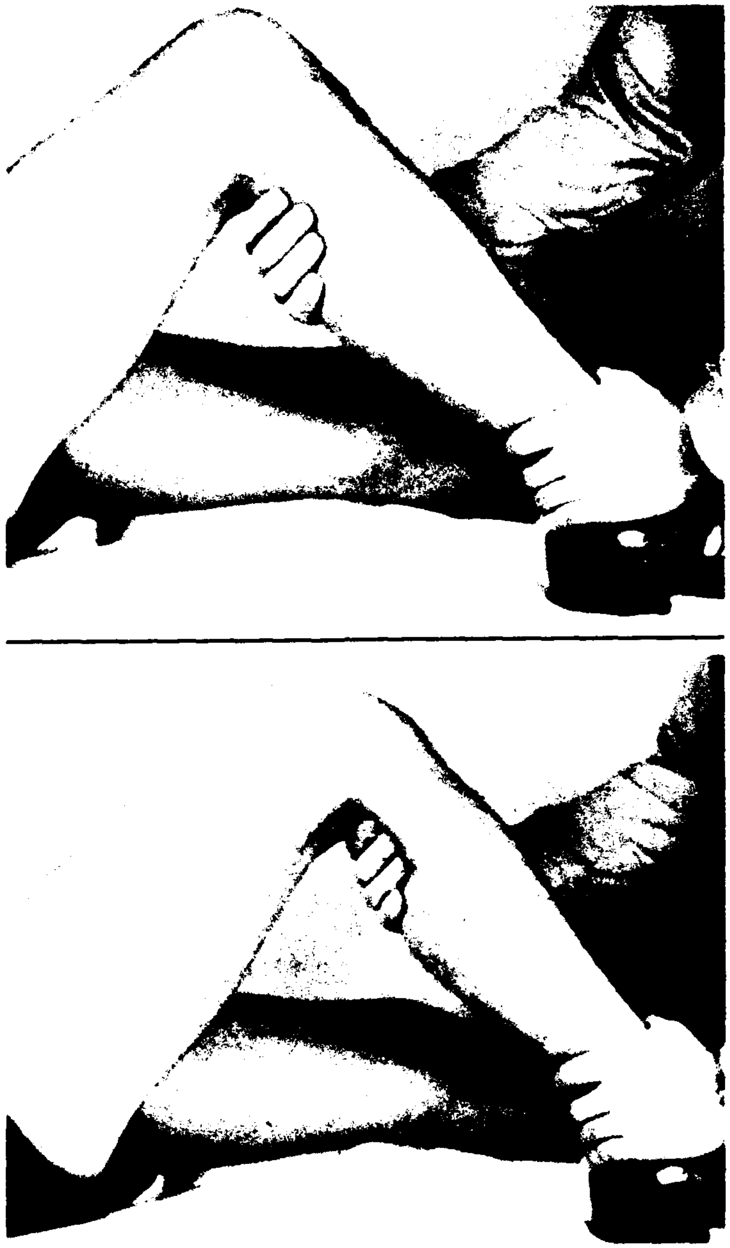

FIGURE 159.—Positive drawer sign in tear of anterior cruciate ligament. (Top) Neutral position. (Bottom) Forward displacement of leg. (West, F. E.: S. Clin. North America 25: 111–135, February 1945.)

fibular insertion of the ligament. If the peroneal nerve was involved, there was appropriate sensory and motor loss. Chronic relaxation of the lateral collateral ligament did not cause as much disability as relaxation of the medial collateral ligament because the outer aspect of the joint is well protected by the biceps femoris muscle and the iliotibial band. Marked

relaxation of either of the collateral ligaments was associated with some fractures. Also avulsion chip fractures of the extra-articular and lateral surfaces of the condyles suggested the abduction or adduction that was present in rupture of the medial or lateral collateral ligaments of the knee joint.

The cruciate ligaments.—Injury of the anterior cruciate ligament sometimes occurred as an isolated phenomenon when the leg was extended and the knee was forced into hyperextension. When this mechanism was operative, the posterior capsule was stretched and rupture of the anterior cruciate ligament followed. Injury of the anterior ligament could occur also when the knee was flexed and there was forced posterior displacement of the tibia. Avulsion of the bone was then possible at the tibial origin of the anterior cruciate ligament.

Some observers believed that rupture of a cruciate ligament could not occur without simultaneous injury to the collateral ligaments. Injuries of the anterior cruciate and medial collateral ligaments frequently occurred in association.

If rupture of either of the cruciate ligaments occurred, the patient complained that his leg had "given way." Otherwise, in contrast to injuries of the collateral ligaments, which were disabling, injuries of the cruciate ligaments inconvenienced the patient only when he was descending stairs.

Diagnosis of injuries of these ligaments was made by the history; the presence of a synovial effusion, which was frequently considerable and hemorrhagic; and a positive drawer sign. This sign (fig. 159) was considered essential to the diagnosis. With the leg flexed at a right angle, abnormal mobility could be demonstrated anteriorly if the tear was of the anterior cruciate ligament. If the posterior cruciate ligament was affected, the tibia could be displaced backward on the femur to an abnormal degree. Comparative tests were carried out on the intact leg. Hemarthrosis and spasm of the hamstring muscle frequently impeded the diagnosis. If aspiration did not correct the situation, the examination was carried out under anesthesia, to relax the spasm.

Extremely careful roentgenographic examination was necessary because many injuries of the cruciate ligaments were associated with avulsion fractures.

MANAGEMENT

Before World War II, most orthopedic surgeons held the view that surgical repair of injured ligaments of the knee joint, because its results were so poor, should be resorted to only when a thorough regimen of conservative treatment had failed. The wartime experience confirmed this pessimistic view, and, indeed, strengthened it. An operation that might have given acceptable results for a man in a sedentary occupation in civilian life would have been rated a failure for a soldier required to perform full military duty. All acute injuries encountered in service were usually given

a trial of conservative therapy unless the tear was obviously so severe and instability of the knee so likely to be disabling that immediate surgery had to be considered.

Minor sprains and injuries of the medial collateral ligaments that were not severe (that is, that did not show marked separation of joint surfaces on the abduction test) were aspirated and immobilized in a cylindrical cast for 2 months, with the knee in almost full extension and with correction of any valgus deviation. Quadriceps exercises were an important part of the treatment. When the cast was removed, a wedge (¼-inch) was applied on the inner side of the heel of the shoe. Injuries of the lateral collateral ligament were treated similarly except that the wedge was placed on the outer side of the heel. It was important for immobilization to be maintained long enough for complete healing of the tear before unrestricted weight-bearing was permitted.

Therapy was the same in principle for injuries of both the anterior and the posterior cruciate ligaments. The head of the tibia was pushed backward in anterior injuries and pulled forward in posterior injuries. Quadriceps exercises were again of major importance.

In deciding on the mode of treatment, certain facts had to be borne in mind:

1. Psychoneurotic evaluation was even more necessary in operations on the ligaments, in which results were dubious at best, than in other operations on the knee.
2. Old tears and unstable knees responded poorly to surgery. More was to be gained, on the whole, by vigorous exercises to strengthen the quadriceps apparatus than by operation. Ligamentous repair was, therefore, undertaken only after the patient clearly understood that arthrodesis might ultimately be necessary.
3. The reconstructive operations devised for repair of the ligaments were ingenious, but the fascia lata substitutes which most of them used stretched readily, and the end results were no better than were achieved by conservative measures.

ANALYSIS OF CASES

The surgical procedures carried out in the 32 tears of the ligaments in the collected AAF cases were as follows (*12*):

1. Primary suture of the cruciate ligaments in three cases. Operation was performed a few days after injury, with strips of fascia lata, but results were good in only one case. In the other two cases, the ligament ends frayed and there was loss of ligamentous substance. In another case, not included in this series, a fragment of bone separated with the ligament at its tibial anchorage, but it was simple to re-anchor the fragment, and the result was good.
2. The Hey Groves operation in six cases. In these operations on the cruciate ligaments, fascia lata or tendon was drawn through holes in the external femoral condyle and the internal tibial condyle. The knees appeared stable at the end of 6 to 12 weeks of immobilization, but with the resumption of knee function, the transplanted fascia or tendon stretched and the former instability returned in every instance.
3. Transplantation of the gracilis tendon in five cases. In this technique, used on the cruciate ligaments, the tendon was severed at the proximal end and left attached distally. A procedure similar to that originally described by Hey Groves was employed

in directing this tendon between the tibial and femoral condyles. The end results in these cases are not known, but the prognosis was not hopeful.

4. Plastic procedures on the collateral ligaments, usually the medial collateral ligament, in 16 cases. A variety of techniques were used, and while the end results are not known, the prognosis was again not considered hopeful.

5. The Mauck operation in two cases. In this operation, the lower attachment of the medial collateral ligament is transplanted downward on the tibia with a fragment of bone.

End results are available in only 17 of these 32 operations. They are depressing; 10 patients were separated from service on CDD, and seven were reclassified to limited duty. Attempts to protect the knee while patients were in any sort of service were not practical, and in a number of instances, a fresh injury or a recurrence converted what at first promised to be a fair result into a poor one.

Some of the poor results in this series were caused by traumatic osteoarthritic changes that developed as the result of multiple daily traumas from slight to moderate subluxations. In extremely unstable knees, these changes were evident on roentgenologic examination in the course of 2 or 3 years. They sharply limited the patients' endurance.

The Army results in injuries of the ligaments duplicated the Canadian experience (*39*). Early in the war, Canadian medical officers observed that in ligamentous tears, especially tears of the medial collateral ligament, symptoms often returned in 4 to 6 months after treatment, and the pain and disability left no choice except separation from service.

Section IV. Sprains, Dislocations, and Fractures

SPRAINS

Sprains of the knee encountered in Zone of Interior hospitals varied from the simple type caused by a sudden movement or quick twist of the knee to the very severe types that included injuries of cartilaginous surfaces. The latter variety were frequently discovered late, when recovery from a presumably simple injury did not occur normally. The degree of sprain was influenced by the type of terrain on which it occurred, the severity of training, and the amount and kind of equipment carried.

The diagnosis of sprain should never have been made until fractures were excluded by roentgenologic examination. By the end of the war, it seldom was.

The simplest and commonest variety of sprain involved only a small area of one ligament. Recovery usually occurred in a few days with the application of an elastic bandage, physical therapy in the form of heat and massage, and active motion.

The more painful and persistent variety of sprain, as well as all sharply

localized sprains, were relieved rapidly by local injection of 1 to 3 cubic centimeters of 1-percent Novocain. A single injection was usually sufficient. A vasoconstrictor was not used. The average period of disability was 5 to 10 days.

When the sprain was accompanied by an effusion, particularly if hemarthrosis was present, the fluid was aspirated and a posterior splint was applied, in about 15 degrees of flexion, until pain was relieved, which was usually within 2 to 5 days. Meantime, icecaps helped to relieve pain and to prevent recurrence of bleeding. When the splint was removed, an elastic bandage was applied, but active motion was not permitted for 12 to 14 days after injury. Recovery was likely to be slow, and return to duty was seldom possible until 4 weeks or more had elapsed.

The cases just described were those in which cartilaginous injuries sometimes became evident later. Unless locking had occurred, it was impossible at the time of injury to establish or rule out associated injuries of the menisci or cruciate ligaments.

The most important phase of treatment of all sprains was the prompt initiation and faithful use of quadriceps exercises. Without them, even in simple sprains, muscle atrophy might lead to recurrent synovitis and to a prolonged period of disability.

It was usually possible, without too much difficulty, to differentiate clinically between serous and hemorrhagic effusions. In the former, the accumulation of fluid was slow and the joint did not become tense promptly, as it did in an hour or two when there was intra-articular bleeding.

At the station hospital at Camp Butner, Durham, N.C., Lt. Col. George M. Dawson, MC, and Maj. Thomas F. Dempsey, MC (*40*), were dissatisfied with the long period of hospitalization and slow recovery achieved with the standard treatment of serous and hemorrhagic effusions. In 23 cases treated in this manner, the period of hospitalization ranged from 17 to 125 days and averaged 47.7 days. In their next 27 cases, they used the acid-ash, low-salt, ammonium-chloride method described by Pelner in 1943 (*41*), supplemented by light applications of X-ray. In 16 cases of serous effusion, absorption occurred in 3 to 22 days, an average of 15.6 days. The period of hospitalization ranged from 4 to 30 days, an average of 15.6 days. In 11 cases of hemarthrosis, absorption occurred in 7 to 24 days, and averaged 11.6 days, while the period of hospitalization ranged from 11 to 36 days and averaged 18.2 days.

This method does not seem to have been used at any other Zone of Interior hospital.

DISLOCATIONS

In civilian life, abnormalities of the patella were usually of little importance. In military service they were important because they tended to produce dislocations.

Dislocations of the patella were always to the outer (lateral) aspect of the knee. Etiologically, they were of three different types (*16*):

1. The congenital type of dislocation often occurred without a definite history of injury. The chief finding was the tendency of the patella, when the knee was flexed, to ride over the lateral femoral condyle, which was frequently poorly developed. In such cases, the infrapatellar ligament was likely to be abnormally long, and there was a tendency to genu valgum and genu recurvatum, with relaxation of the medial or internal portion of the capsule.

2. Traumatic dislocations might result from direct injury that occurred when the tibia was abducted and externally rotated at the same time that a forceful contraction of the quadriceps muscle occurred. A shearing force that struck the patella from its inner aspect might also be responsible for the dislocation. If the patella was of the flat type, a direct lateral blow could produce an osteochondral fracture as well as a dislocation. Factors which predisposed to such injuries included a high femoral condyle, laxity of the capsule, and a tendency to knock-knee.

Associated tears of the medial collateral ligament were common. Tears of the anterior cruciate ligament occurred occasionally.

Clinical findings, which were meager after reduction, included tenderness over the inner margin of the patella and synovitis.

3. Recurrent dislocations were most often observed in patients with neglected or uncorrected weakness of the vastus internus or with a rather pronounced knock-knee deformity. In such patients, a sudden contracture of the quadriceps muscle, which caused a lateral pull on the patella while the knee was flexed, might produce a dislocation. Chondromalacia of the patella and arthritis of the patellofemoral joint were frequent in recurrent dislocations.

Clinically, it was sometimes extremely difficult to demonstrate slight degrees of instability, but axial roentgenograms revealed even minute variations in the normal patellar movement.

Treatment of an acute dislocation of the patella was simple. Immobilization was instituted after reduction, which often had already been accomplished, spontaneously or otherwise, when the patient was first seen. The knee was maintained in extension in a cylindrical cast for 2 months, during which time quadriceps exercises were carried out routinely.

Recurrent dislocations or subluxations were caused by structural weakness or, in wounded soldiers, by weakness of the vastus internus or by wounds that had resulted in damage to this muscle and in an imbalance of the muscle pull. Simple excision of the patella was of no value in such cases without other corrective measures, particularly the treatment of chondromalacia if it was present (p. 655). Otherwise, slipping of the quadriceps tendon and the patella would persist.

Conservative measures were of no value in congenital dislocations, but before surgery was undertaken in these injuries, careful evaluation of the primary lesion and associated lesions was necessary. If the lesion had been aggravated during service, the soldier had a right to surgery if he wished it. Otherwise, discharge on a CDD was the best plan.

Plication of the internal capsule, combined with excision of the patella or medial transplantation of the tubercle with the patellar tendon, was the preferred treatment for congenital dislocations. In some cases, it was

necessary to elevate the lateral femoral condyle (the Albee operation). If a knock-knee deformity was present, it might be necessary to correct it by osteotomy.

FRACTURES

Civilian-Type Fractures

In spite of the vulnerability of the patella to injury because of its exposed location, fractures in training camps were less frequent than might have been expected. They were of all varieties.

Management.—Those fractures without displacement and separation of the fragments (fig. 160) were treated with a simple cast or were not immobilized at all. Guarded early motion was permitted, though without weight-bearing for the first 4 weeks.

If the fragments were widely separated and grossly displaced, open reduction was indicated, with suture repair whenever possible with catgut, silk, linen, kangaroo tendon, wire, or fascia lata. Metallic fixation was undesirable and was seldom used, on the principle that the less hardware in the patella, the better from every standpoint.

If comminution was extreme, the best results were achieved by excision of the totally detached and useless fragments and suture of the major intact fragment with fascia, to reestablish the continuity of the quadriceps extensor apparatus. Partial excision of the patella at one pole or the other was a highly satisfactory technique, though for some reason, it was not generally popular. Either the patellar or the quadriceps tendon, as the circumstances required, was sutured to the remnant of the patella. Maj. (later Lt. Col.) Robert P. Kelly, Jr., MC, believed that stability was better if the lower pole could be left in situ. He mentioned, however, three cases observed at Ashford General Hospital, White Sulphur Springs, W. Va., in which excellent stability was present after the lower pole had been excised.

FIGURE 160.—Comminuted fracture of tibia and transverse fracture at lower pole of patella. This soldier sustained these injuries in a motor vehicle accident on 4 June 1945, in an overseas theater. Treatment consisted of debridement and delayed primary closure. His wound was healed when he arrived in the Zone of Interior. A. Lateral roentgenogram of right lower femur, knee, tibia and fibula, taken at 51st Evacuation Hospital and showing comminuted fracture of tibia extending into knee joint and transverse fracture at lower pole of patella. B. Lateral and anteroposterior roentgenograms of same leg and knee, taken on 27 September 1945 at Lovell General Hospital, Ayers, Mass., 8 weeks after patient's arrival there and 16 weeks after injury. At this time, the comminuted fracture of the tibia into the knee joint is seen to be firmly united. There is only slight narrowing of the joint space on the lateral side. C. Lateral photograph of leg and knee to show range of motion at this time. Extension is to 175 degrees, 5 degrees less than full extension, and flexion is possible to 130 degrees.

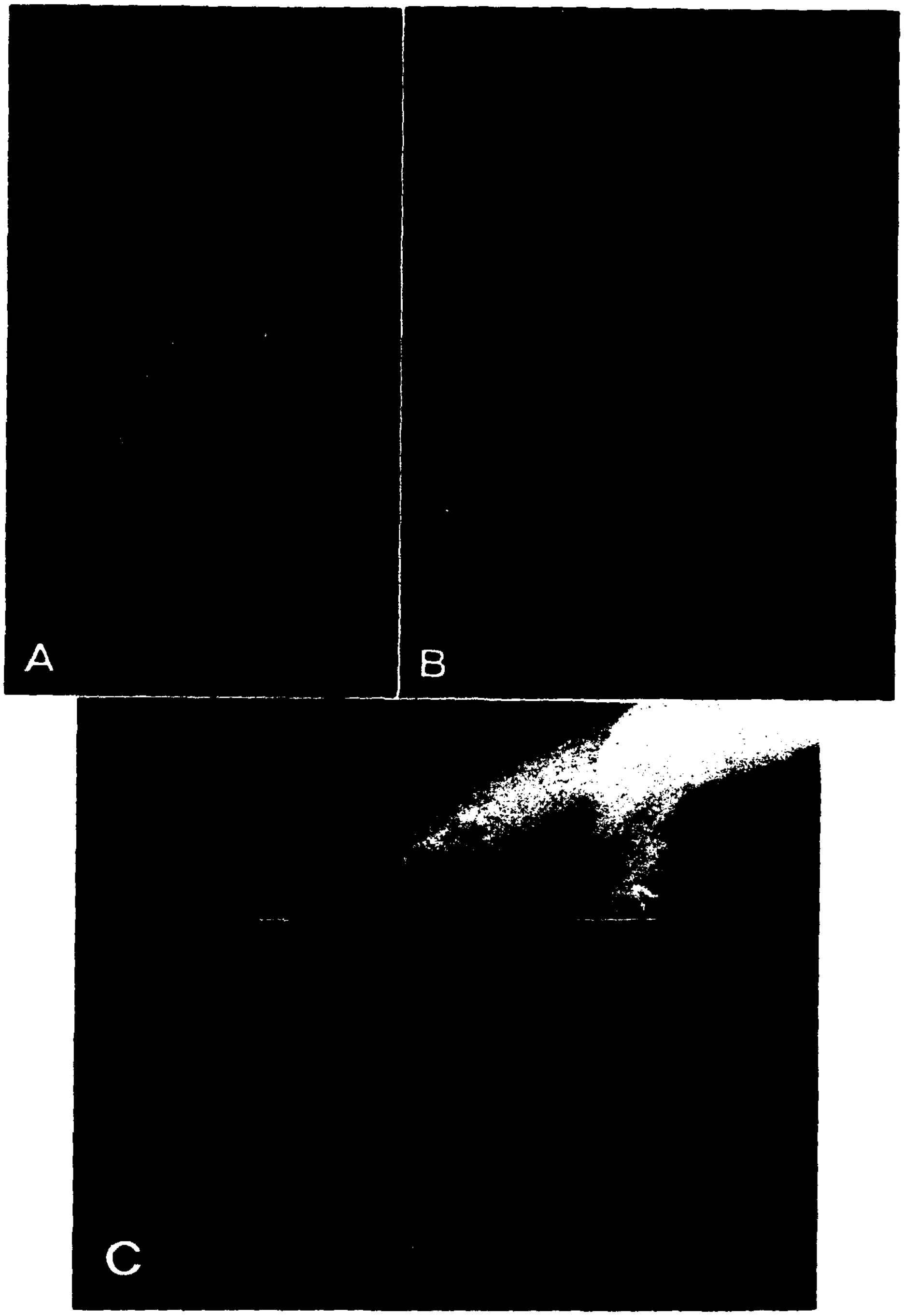

FIGURE 160.—*See opposite page for legend.*

Case 2.—In a particularly badly comminuted fracture observed at the station hospital at Camp Maxey, Tex. (*42*), 10 days after the original injury, the fracture extended into the knee joint and was complicated by a transcervical fracture of the femur on the same side and a considerable

skin loss. Synovial fluid was draining from the wound in small quantities. The femoral fracture was grafted and pinned with a Smith-Petersen nail. The capsule was repaired by a plastic procedure, and a split-thickness skin graft was applied over the defect. Two weeks later, some of the smaller fragments of the patella were excised and fascial repair was carried out. Results of these conservative measures were good. There was no loss of extension, and final flexion was 85 degrees. The femoral head was viable by roentgenogram though its eventual fate could not be predicted. The patient's comparative youth was, of course, in his favor.[5]

Total excision of the patella.—At the AAF conferences in 1943 (*14*), there was vigorous discussion concerning the value of both partial and complete removal of the comminuted patella. The report from one general hospital of four complete removal operations with loss of full extension in all four cases was enough to dampen the enthusiasm of the participants for this procedure.

Most orthopedic surgeons considered it a last resort. In contrast, Maj. Adolph A. Schmier, MC (*43*), from the experience at Northington General Hospital, Tucaloosa, Ala., considered that the only injections to total patellectomy were the cosmetic change in the knee and the loss of normal prominence of the patella. In two of the six cases he reported, in addition to the extreme comminution of the patella, the articular surface of the femoral condyle was fractured. Motion and quadriceps drill were begun shortly after the operation, and the patients walked without support or dressings within 2 to 3 weeks. When they left the hospital, most of them could walk long distances, climb stairs, squat on both heels, and arise from the squatting position with ease. The discomfort felt when they knelt for the first time was only transient. In every case, the result was a strong, normally mobile and stable knee, and one of the patients, a paratrooper, returned to jump duty.

In contrast, patients treated by reduction and immobilization in plaster remained in the cast for 4 to 6 weeks and then had a long period of physical therapy and reconditioning. As a rule, it was 4 to 6 months before any strenuous activity was possible, and return to full duty could not be considered.

Combat-Incurred Injuries

The high degree of comminution observed in combat-incurred fractures of the patella was a decided contrast to the degree usually observed in civilian-type injuries (figs. 161–163). Moreover, at operation, comminution was frequently found to be more extreme than had been indicated either clinically or by roentgenograms.

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[5] In transverse fractures of the patella, the medial and lateral portions of the capsule of the knee joint are badly torn and extremely careful suture of the capsule is mandatory.—M. C.

FIGURE 161.—Management of comminuted fracture of upper right tibia extending into knee joint. This soldier was wounded by shell fragments on 25 September 1944. The wound was debrided overseas, and a month later, a dermatome skin graft was applied to the popliteal region, which had been denuded of skin. On 25 April 1945, incision and drainage of the knee joint were performed. When the patient arrived at Lovell General Hospital, Ayers, Mass., on 28 September 1945, the wound of the right thigh was healed, but there was a small draining sinus over the anterolateral aspect of the tibia. He was bearing full weight on the injured knee. (Top) Anteroposterior and lateral roentgenograms of right knee and adjacent bones on 4 October 1945, showing healed comminuted fracture of upper tibia extending into knee joint. (Bottom) Lateral photograph of leg and knee showing full extension at 180 degrees with flexion to 150 degrees—approximately 30 degrees of motion. The outcome of this case to date represents salvage of a knee joint which became infected, with definite osteomyelitis of the tibia. Subsequent sequestrectomy may have been necessary.

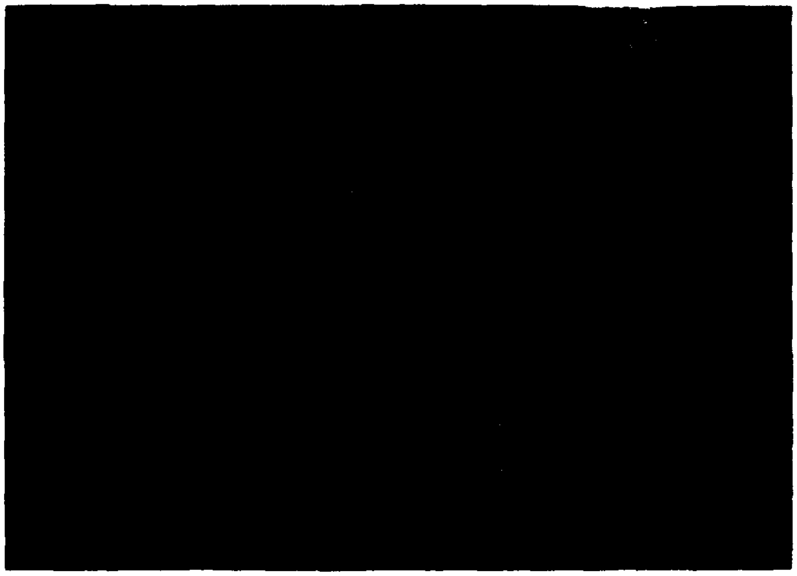

FIGURE 162.—Lateral and anteroposterior roentgenograms of knee joint on 23 November 1944, showing marked fragmentation of femur, patella, and tibia. Note metallic foreign bodies in situ. Because of the complete disintegration of the knee joint, with no motion at the knee and a flexion deformity of 15 degrees, knee fusion was considered mandatory and was performed on 23 April 1945. Ten weeks after operation, the wound was completely healed and the soldier was ambulatory without pain in an arthrodesis brace.

The immediate management of combat-incurred wounds of the knee is presented in full in other volumes in this historical series (*17, 18*). When the patients were received in the Zone of Interior, surgery had frequently been carried out, and the patella had often been removed in toto on the indications of contamination at injury or fragmentation. Flexion was usually good, but some degree of extension was usually lost.

Perforating wounds of the lower end of the femur involving the knee joint were extremely difficult to treat, not because of infection, which was seldom a problem in combat wounds in World War II, but because of traumatic loss of the condyles. When the lateral condyle was destroyed, the subsequent disability was much greater than when the medial condyle was missing. In either event, complications included traumatic arthritis and increased fibrosis of the capsule and surrounding tissues, with resulting deformity and functional disability. The question in such cases was whether the patients would be better served by a fusion procedure than by arthroplasty or merely by the use of braces.

Infected wounds, as just noted, were infrequent, but when infection was present, if the patella was still in situ, it frequently became partly or completely fixed to the femur, with resulting loss of joint mobility.

One of the more resistant defects in combat-incurred injuries of the

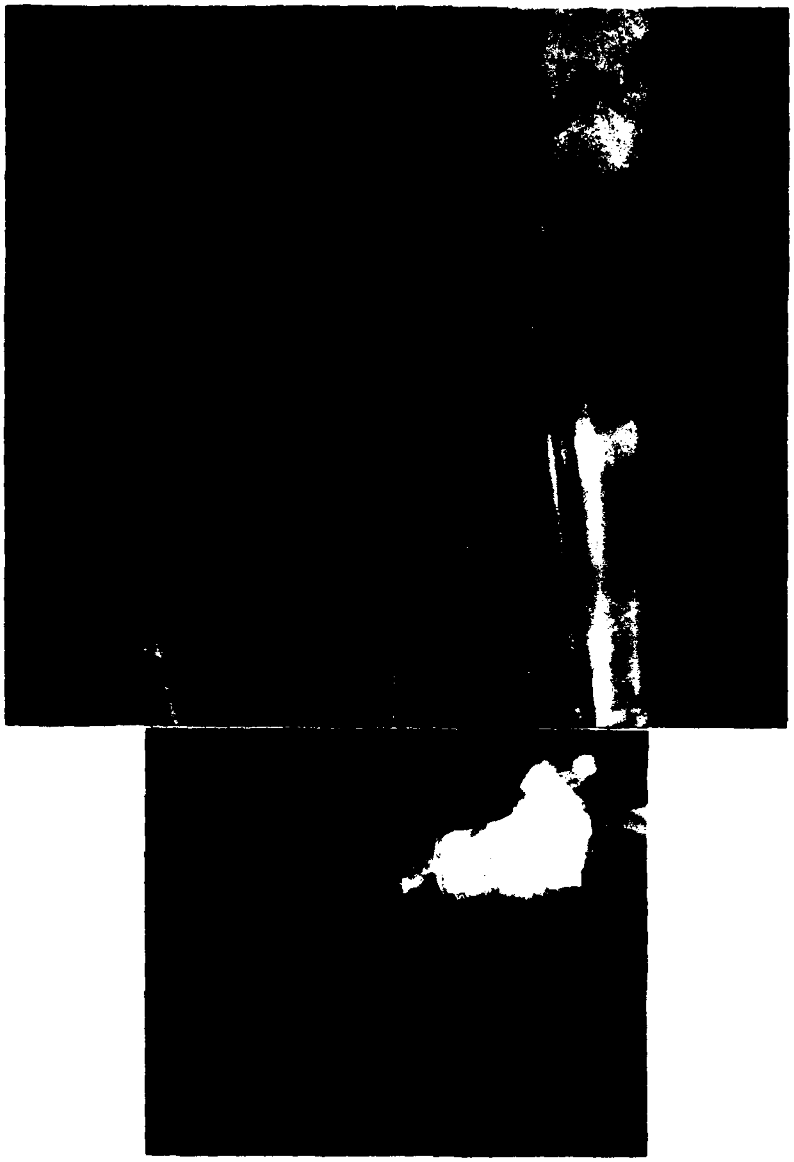

FIGURE 163.—Fractures about left knee. This soldier was wounded by enemy rifle fire on 21 January 1944. At the 52d Evacuation Hospital, debridement was performed and a circular plaster-of-paris splint was applied. At Lovell General Hospital, Ayers, Mass., in September 1945, sequestrectomy was performed, and an abscess was incised and drained the following month. (Top) Anteroposterior and slightly oblique roentgenograms of left knee, upper third of tibia and fibula, and lower end of femur on 18 October 1945, showing healed fractures at articular surface of lateral femoral condyle, adjacent tibia, and elsewhere in upper tibial shaft. (Bottom) Lateral photograph, several weeks later, showing range of motion in knee from 180-degree extension to 100-degree flexion. Though drainage persisted, the soldier was ambulatory without any support and without pain. This was excellent salvage of a seriously injured knee joint.

knee was sinus formation extending into the cancellous bone of the femoral condyles or the upper end of the tibia. Small sinuses tended to close, or

almost close, spontaneously, but large cavities did not. It was sometimes possible to collapse the overlying bony roof and thus achieve closure, but in many cases, curettage and packing were necessary, followed later by split-thickness skin grafts.

Combat-incurred injuries of the knee frequently ended in partial ankylosis, the underlying cause being a combination of an infectious process and bony destruction of the articular surfaces.

End Results

Results of nonunion, malunion, and fibrous union in fractures of the patella were particularly unfortunate. The knee was left weak, undependable, particularly on stairs, and often painful. Refracture was estimated at 10 percent. It could occur without trauma, merely with a sudden, strong contraction of the quadriceps. The majority of refractures occurred within the first year after injury, but they could occur many years later. Some observers, basing their opinions on their civilian experience, believed that patients with fractures of the patella were likely to do well for a period of years, but then tended to develop bursitis, elongation of the quadriceps, loss of full extension, and generally unstable knees.

Note.—A special type of instability of the knee observed in paratroopers is described under that heading (p. 221).

Section V. Other Special Conditions

HYPERTROPHY OF INFRAPATELLAR FAT PADS

As in civilian practice, so during World War II many instances of hypertrophy of the infrapatellar fat pads were overlooked simply because the diagnostic possibility was not considered. Not very many were reported. There were 15 in the 190 arthrotomies performed at Camp Roberts (*29*), but only two (in addition to two injuries to the pad) in the 150 arthrotomies performed at Camp Crowder (*24*). In the 1,411 internal derangements of the knee that make up the AAF series (*12*), there were 66 instances of interposed and hyperplastic fat pads, the proportion in this series suggesting that this condition may be more frequent than is generally realized.

A typical history revealed a gradual onset, transient episodes of pain or aching, and sometimes a sudden giving way of the knee while the patient was walking. The pain was often well localized anteriorly, but was referred with less intensity to the rest of the joint. It was sometimes severe enough to cause guarded motion. Diffuse swelling was frequent. The mechanism of strain and torsion characteristic of tears of the menisci was generally

absent, and there was no story of locking. In spite of the absence of these symptoms and signs, a mistaken diagnosis of torn meniscus was often made before operation, as it was in six of the 15 operations at Camp Crowder, though in every instance, these structures were found intact at operation.

A precise diagnosis of hypertrophy of the fat pad was possible only by surgical exploration, which was not justified until other pathologic changes had been ruled out. It was characteristic to find at operation a well-defined tongue of the hypertrophied fat pad between the femoral and the tibial condyle, which made it easy to understand the mechanism of the clinical picture. The portion of the femoral condyle in contact with the interposed tab frequently was eroded. It was most important that the whole joint be explored before any surgery was undertaken; otherwise, normal menisci might be removed and the hypertrophy of the fat pad remain undiscovered. Surgery was limited to excision of the interposed fat tag.

In the 15 operations at Camp Roberts, the average age of the patients was just over 25 years. On the average, they wore splints for 2½ days, walked in 6 days, achieved 90-degree flexion in 10 days, could squat on their heels in 24 days, and were returned to duty in 31 days. Although the results in this small series were considered unusually good, functional recovery was rather slow, one reason being the soreness, swelling, and synovitis that occurred as a reaction to surgery. Three patients had to be reclassified, because of chronic synovitis in two cases and pain, without positive physical findings, in the third case. The other 12 patients were returned to full duty, and when last heard from at various periods of time (months) after operation, they had gone through the full training schedule, including drill and obstacle course, without difficulty.

LOOSE AND FOREIGN BODIES

Osteochondritis dissecans was responsible for half or more of all the foreign bodies encountered in the knee joint, but the other objects found in it covered a surprisingly wide range. They included pieces of torn cartilage; detached fibrous or lipomatous papillae; detached hypertrophic synovial villi; organized hematomas; sequestra from osteomyelitic processes; tumors of the capsule; and objects originating in such conditions as arthritis deformans, Charcot's joint, tuberculosis, and gout. Foreign bodies of external origin also were present, in addition to bullets, shell fragments, or other missiles in combat-incurred injuries. Two of the patients in the Camp Crowder series had fibrous masses in the joint, one loose in the intracondylar area and the other attached to the lateral meniscus. In the latter case, in spite of a residual disability (flexion limited to 95 degrees), the patient was considered of military value and he was returned to full duty after operation.

It was not always possible to identify the type and origin of these loose

bodies. In the 89 cases in the Luck series not originating in osteochondritis dissecans, 63 had to be listed as idiopathic. Trauma to the articular surface of the femur was responsible for six of these cases; a direct blow on a margin of a femoral condyle sheared off a fragment of articular cartilage and underlying osseous cortex. In 15 other cases, a direct blow on the patella separated a fragment of cartilage and cortex, which in one instance amounted to a third of the articular surface of the patella. It was speculated that other cases of the kind just described might be included in the 63 idiopathic cases, but it was impossible to be definite when patients were seen months and years after the original injury.

If the loose object was the only pathologic finding, the results of its removal were generally good and the patient could be restored to full duty.

OSTEOCHONDRITIS DISSECANS

General Considerations

Osteochondritis dissecans was found in a rather surprising number of patients after very slight injuries to the knee. Two relatively large series of cases observed during World War II are available for analysis:

Ninety-seven cases included in 186 instances of loose foreign bodies in the knee joint in the collected Luck cases (*12*).

Forty-seven cases included in 77 instances of foreign bodies observed by Lt. Col. John H. Gilmore, MC (*44*), at the William Beaumont General Hospital, El Paso, Tex., in 1,652 roentgenologic examinations of the knee over a 2-year period. In 26 of the 47 cases, classical evidence of the disease was found on the roentgenograms. There were also two instances of this disease in 810 roentgenographic examinations of the ankle and one in 466 examinations of the shoulder.

In the Luck series, the subchondral fragment was completely separated from its bed in 63 cases and still attached to it in the other 34. It had remained as a single object in 53 of the 63 cases and had broken into two or more objects in the other 10.

More than half (99) of the 186 patients with loose bodies in the knee joint in this series were known to have had these objects in situ before they entered the Army Air Forces. In 67 cases, it was known that their presence was a line-of-duty development; in the other 20 cases, their origin could not be determined. In the total series, the duration of symptoms varied from a month or less in 10 cases to more than a year in 53; the duration was not known in the other 91 cases. The shorter the duration, the more likely was trauma to be the etiologic factor.

In the Beaumont General Hospital cases, the lapsed time from injury to consultation ranged from 2 to 18 years in the 40 cases in which these data were known.

In both series, the most frequent site of the lesion was the lateral aspect of the medial femoral condyle, but it was also encountered on the articular surfaces of the medial femoral condyle, the patella, and the tibial plateau.

Etiology

The etiology of osteochondritis dissecans was unknown in civilian practice and the military experience threw no light upon it, other than furnishing further support for its traumatic origin. In three cases in the Beaumont General Hospital series, in all of which a history of trauma was absent, clinical complaints had begun gradually, from 5 weeks to 4 years before the patients were seen. In one of these cases, when the contralateral knee became stiff after operation on the first knee, an almost identical focus of osteochondritis dissecans was discovered in it; the pathologic changes and roentgenologic findings did not differ from those in instances of known traumatic origin.

It was assumed that impairment of the blood supply, with a resulting focus of avascular necrosis, explained the detachment of fragments from their bed.

Clinical Picture and Diagnosis

Patients were seldom seen in the earliest stages of this disease, when the symptoms were transitory synovitis, which was more frequent when the object was loose in the joint; vague discomfort; and slight loss of extension. Pain on walking, swelling, and locking of the joint if a loose body (bodies) was present were the usual reasons for consultation. Symptoms that were mild in civilian life were likely to become exacerbated under the strains of military training and Army life.

In the 47 cases in the Beaumont General Hospital series, pain was complained of in 40 cases, swelling in 19, limitation of motion in 17, locking of the joint in 14, and crepitus in five. In seven cases in which roentgenologic findings were positive, there was no complaint of pain. The clinical manifestations in these cases were those common to any internal derangement of the knee. The diagnosis was confirmed in all the surgical cases in the series, but in every instance, it was based on roentgenologic observations, not clinical or physical findings.

Routine roentgenologic examination included anteroposterior and lateral projections, supplemented by projections to show the femoral intercondylar notch and such oblique films as were necessary in the special case. Views of the intercondylar notch sometimes showed the lesion before the fragment was detached. Studies were also made in the Waters position, to show the superior-inferior aspect of the patella. Slight overexposure was

sometimes useful. When a loose body was identified by roentgenograms, if surgery was being considered, a splint was applied at once, to prevent the migration of the object to another position before it could be removed.

Management and Results

When osteochondritis dissecans was encountered early in the war, it was the practice to open the joint and remove the fragments. As time passed, however, it was found that, in many instances, arthritic changes had occurred and would preclude full duty for these patients. If roentgenographic examination had been a part of the induction routine, most of the men with this condition would probably have been rejected. It, therefore, became the policy, if arthritis of any degree was present, not to operate unless a fragment had so locked the joint that only surgical removal was possible, or other special circumstances existed, or the man was of definite military value.

If surgery was carried out, removal of the loose body was usually all that was necessary. If the diagnosis had been made before complete sequestration, the area of softened cartilage was completely resected along with the loosened underlying bone, and the defect in the femoral condyle from which the loose body had been removed was gently curetted.

Recovery was more rapid and the results generally better when the foreign body was removed through a short incision. Long incisions were more likely to be attended with neurotic reactions.

The results of arthrotomy for osteochondritis dissecans varied according to the size and location of the defect of the articular surface, the duration of the disability, and the presence or absence of associated conditions, particularly arthritis. If the fragment was small, there was seldom any disability after the loose body was removed. Full duty was frequently possible. If the defect was large and on a weight-bearing area, endurance was limited, and episodes of pain and synovitis were to be expected. Defects of long standing were likely to be associated with secondary osteoarthritic changes. When there were adjacent areas of chondromalacia (p. 670), full military duty was impossible. In fact, most patients with osteochondritis dissecans of the patella were incapable of any but limited service.

In the 97 operations in the Luck series, there were 14 postoperative complications, including pyogenic infection in three cases, thrombophlebitis in three, and nonsuppurative synovitis in nine. All were eventually controlled.

OSGOOD-SCHLATTER DISEASE

Osgood-Schlatter disease (osteochondrosis of the tibial tubercle) was perhaps the most frequent of a number of relatively uncommon diseases of the musculoskeletal system observed in World War II. It was found 1,912

times in the several million soldiers who were in service (*45*). Of this number, 1,275 cases were observed in the Zone of Interior. Pain and disability usually persisted with conservative treatment or with the various forms of surgical treatment in vogue in civilian practice, and it eventually became the policy either to reclassify patients with this disease or to separate them from service on CDD.

BURSITIS

The various bursae of various sizes about the knee sometimes became the site of chronic, nonsuppurative, inflammatory changes, with accumulation of fluid in various degrees. The changes were manifest clinically by localized pain and tenderness.

Large bursae, especially in the acute stage, were readily diagnosed and treated. Smaller bursae were easily overlooked, especially those located beneath the medial collateral ligament and posteriorly in the region of the tendons of the hamstrings.

When the bursitis had reached the chronic stage, or when calcification occurred within the sac, surgical excision was necessary. If one of the larger bursae was involved, it was necessary to identify its communication with the joint and ligate it; otherwise, a recurrence was possible.

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CHAPTER XXIV

Injuries of the Tibia and Fibula

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

A separate discussion of injuries of the tibia and fibula is not practical because these bones so very often were involved in injuries jointly. Fractures of the fibula usually were simple to handle. Fractures of the tibia were always potentially serious. It is surprising that nerve injuries were not associated with them more often.

TRAINING AND OTHER CIVILIAN-TYPE INJURIES

Fractures of the Shaft of the Tibia

Simple transverse fractures of the shaft of the tibia incurred in training or similar circumstances seldom presented any problems. The standard treatment was immobilization in plaster, and results generally were good.

Compound fractures of the shaft, as well as oblique and displaced fractures, were a different matter, and no hard-and-fast rules were applicable to their management (*1*). Two injuries observed at Camp Maxey, Tex., illustrate the problems that might be encountered (*2*). One patient required a series of plastic operations before bone surgery could be considered. The other was admitted to the station hospital after he had been hospitalized, as an emergency, in a private institution for about a week. At this time, he was febrile and septic, and his wound was grossly contaminated, a condition that was explained when, at operation, a pocket of yellow Arkansas sand was found deep in the wound, between the bone ends. In both of these cases, satisfactory alinement could be achieved. Union was incomplete, but nonetheless it was union, and in both cases, the bone could be reinforced by a Phemister graft applied to the posterior tibia through a posteromedial approach.

At the Army Air Forces conferences in 1943 (*1*), it was generally agreed that for oblique and displaced fractures of the tibial shaft, in which the fragments could not be maintained in alinement by traction, early open reduction and internal fixation were indicated, preferably with a plate and screws. One medical officer recommended that, in long oblique fractures, the fragments be fixed by two to four screws, without a plate. Most of the participants believed that open surgery was far preferable to

the risk of nonunion that might follow distraction of the fragments during traction.

Other observations and recommendations at this conference included:

1. Use of a three-section cast in the treatment of fresh fractures. The upper and lower sections were applied first, and the middle section was added after the fracture had been reduced.

2. Skeletal traction obtained on a fracture table in old fractures of the tibial (or femoral) shaft with overriding. The amount of traction was increased gradually until the overriding was corrected. When plaster was applied, the pins used for skeletal traction were incorporated in it.

3. Fusion of the lower tibiofibular joint for old fractures with tibial deficits. After this operation, the fibula often hypertrophied to sufficient size and strength to bear the body weight.

4. The cautious use of traction on the os calcis in the management of fractures of the lower leg. One participant had observed as much as one-half of an inch of separation between the astragalus and the lower surface of the tibia after traction, and it was his opinion that the stretching of the joint ligaments might result in a premanently relaxed and painful ankle. Another reported subastragalar pain after traction obtained by a Steinmann's pin in the *os calcis*.

Fractures of the Tibial Plateau

Depressed fractures of the tibial plateau, which were usually comminuted, occurred in both the medial and the lateral condyles of the tibia, frequently en masse. If more than 10 to 12 degrees of lateral motion was present, there was considerable discrepancy of the opposing articular surfaces, and marked depressions were also observed.

The original policy was to treat these fractures conservatively if they were in good position. As time passed, the policy shifted to the use of surgical measures (fig. 164). At the Army Air Forces conferences in 1943 (*1*), a number of plans of management were presented:

1. Placing a bolt through the upper end of the tibia, to maintain the condyles in position after open reduction.

2. Placing a piece of bone under the involved fragment, to elevate it if the fracture was depressed.

3. Use of a hinged cast to permit early motion, though weight-bearing was not allowed for 3 months.

4. Removal of the meniscus adjacent to the fracture site at open reduction if it (the meniscus) had been torn. Others recommended this procedure only if the presence of the meniscus caused symptoms after a return to weight-bearing.

5. The Watson-Jones technique (*3*); that is, forcing the knee into varus or valgus, repositioning the fragments with a clamp, then applying a circular cast, with the knee in varus or valgus, and instituting traction through the cast.

A depressed fracture of the tibial plateau was generally disabling, and the man who sustained it was usually separated from service on a Certificate of Disability for Discharge because of the traumatic arthritis that almost invariably followed the injury. He could perform useful work in civilian life, but he was unfitted for the rigors of Army life.

FIGURE 164.—Lateral plateau fracture of tibia with fragment originally displaced into popliteal space. Anteroposterior roentgenogram of left knee, showing healed, reduced fracture after fixation by an autogenous bone graft used as a peg. The Army sergeant was left with a stable knee. (McDowell, H. C.: Reconstruction of the Tibia. [Unpublished data.])

COMBAT-INCURRED INJURIES

Early in the war, patients with combat-incurred compound fractures of the tibia and fibula were returned from overseas with their wounds open and packed, and with many bone fragments missing. During this period, the sulfonamides were used locally as well as systemically. Later, the patients arrived in much better condition, with their wounds closed by delayed primary wound closure, sometimes supplemented by split-thickness skin grafts. Penicillin had become available by this time, and there was no doubt of its beneficial influence, though it should be said again that, like the sulfonamides, it was an adjunct measure and not a substitute for good surgery.

When the patients arrived in Zone of Interior hospitals, the procedure

followed depended upon the status of their wounds, which depended, in turn, upon the treatment they had received overseas. In most cases later in the war, overseas management included efficient first aid, resuscitation with blood and plasma as indicated, antibiotic therapy, debridement, and delayed primary wound closure.

Before reconstructive surgery could be undertaken, preliminary measures had to be instituted, including removal of foreign bodies; the removal of sequestra, which was sometimes necessary several times; and the institution of drainage. An occasional deformity was reduced at these preliminary procedures, but only in very carefully selected cases. Also, before reconstructive surgery was undertaken, careful preoperative preparation was necessary (p. 451), including, if infection was present, measures to overcome the nutritional depletion associated with chronicity.

In un-united fractures and those associated with bone deficits, the usual policy was the application of a full-thickness skin graft, followed by bone grafting after complete healing (p. 404). An excellent program of sliding skin grafts and bone replacement restored many damaged legs to functional usefulness. On the other hand, conservatism was not always the most efficient plan. In injuries of the tibia and fibula associated with nerve damage and tendon and bone deficits, multiple surgery and long periods of immobilization lay ahead, and, in retrospect, amputation soon after they reached the Zone of Interior might have served the interests of some patients better. Data are not available, but there seems little doubt that it was required eventually in some of these cases after the war ended.

SPECIAL TECHNIQUES IN UN-UNITED FRACTURES

The combination onlay-inlay-intramedullary graft developed at Fletcher General Hospital, Cambridge, Ohio, was carried out as follows (*4*):

After routine removal of fibrous and scar tissue in and around the ends of the fragments, the medullary canal was open and all sclerotic bone was removed.

Two donor grafts were used. One was taken from the longer of the tibial fragments (the longer the graft, the more useful it was). The other was taken from the opposite, intact leg; it usually measured 6 to 7 inches by five-eighths to three-fourths of an inch.

The lateral or medial aspect of the damaged tibia was exposed and a thin layer of cortical bone was elevated in both fragments, to serve as the recipient surfaces for the graft from the opposite tibia. This graft was inserted into the medullary canal of the shorter fragment and inlaid into the space created by removal of the donor graft from the longer fragment. The graft removed from the fractured tibia was placed in the prepared area on the lateral or medial aspect, in the manner of an onlay. Bone chips, usually trimmed from the grafts, were placed in the space between the grafts. The onlay graft was covered and held in place by the muscles when the wound was closed.

A long-leg plaster cast was worn from 6 to 8 weeks, then was replaced by an unpadded cast, to which a walking iron was attached. The leg was

kept in plaster for 4 to 5 months, and a brace was worn for another 2 to 4 months. Process of healing was followed by serial roentgenograms.

The original report from Fletcher General Hospital was based on six operations, in all of which the grafts took. Somewhat similar procedures were used in 200 subsequent cases.

At Kennedy General Hospital, Memphis, Tenn. (*5*), the operation used for nonunion of the tibia (and femur) was based on the technique of Hey Groves, by which massive grafts, comprising half of the circumference of the involved bone, were apposed to each other. In other words, continuity of the medullary canal was reestablished by bridging the defect with external surrounding cortex in the form of a cylinder.

The usual measures to insure complete wound healing were carried out. Large soft-tissue and bone defects were treated by early saucerization and split-thickness skin grafting by the Kelly technique (p. 297), followed by full-thickness grafts (pedicle, tube, or local skin flap). Definitive surgery was deferred until at least 3 months after complete wound healing. Supervised exercises and other measures to improve the circulation and muscle tone were engaged in during the interim; motion at the site of nonunion was not regarded as harmful since the bone ends were deeply embedded in dense fibrous tissue.

The surgical approach depended upon the location of cicatricial tissue. The shaft of the affected bone was exposed subperiosteally above and below the defect, and dissection was continued down to it. All scar tissue that could be excised was removed and the bone ends were cut back to normal. Healthy bone ends were squared by a hand saw. The defect was measured while longitudinal traction was applied and the necessary pattern and length of the grafts were determined. Longitudinal cuts were made in the superficial cortex with the hand drill and narrow osteotome, care being taken to preserve the periosteal sleeve and to complete crosscuts through half of the bony circumference before cutting through the deep cortex longitudinally. If this technique was not followed precisely, there was risk of splitting the shaft of the bone through the adjacent joint. After multiple drill holes had been placed along the plane of the desired cut in the deep cortex, the deep cortex was cut from the site of the defect toward the crosscut by osteotomes and mallet. The grafts were then rebedded as planned and were fixed firmly with screws. The periosteum was closed over the site of the proximal and distal fragments to the site of repair, where there was no periosteum. Iliac bone was used to fill residual donor defects in order to accelerate osteogenesis.

A single plaster spica was worn for 10 weeks and a long-leg walking plaster, for another 8 weeks. Whether another walking cast was applied at this time or a brace was fitted depended upon progress in the individual case.

This technique proved applicable not only to large defects of the tibia (and femur) but also to small defects caused by interposition of fibrous tissue between fracture fragments and sclerosis of bone ends. If this extraneous tissue was removed, some shortening resulted, and osteotomy of the fibula was required. If, on the other hand, this tissue was not removed, integrity of union had to be secured by onlay or inlay grafts,

and experience showed that fractures thus treated tended to refracture on slight provocation.

Results in nine tibial and three femoral grafts applied by this technique between December 1943 and June 1945 at Kennedy General Hospital were considered good. Serial roentgenograms showed the apposing massive half-cylinder grafts firmly fixed to the host bone and to each other.[1]

WEIGHT-BEARING

The time at which a fractured tibia was ready for weight-bearing was an important consideration. It depended upon the anatomic location of the fracture, its character, the ordinary physiologic considerations of bone healing, and the clinical and roentgenographic evidence present in the individual case.

Weight-bearing could be begun advantageously almost immediately in a simple transverse fracture of the tibia, perfectly reduced, before union was firm. This was not true of more complicated injuries. Early weight-bearing with the idea of hastening bony union resulted, instead, in mobility at the site of the fracture, with subsequent delayed union or nonunion. After the fracture had become frozen, weight-bearing undoubtedly hastened final union. Reconditioning was a valuable form of therapy, but in tibial fractures, it had to be used cautiously, especially in the early weeks of the injury.

Roentgenograms were made immediately after the postoperative plaster cast was applied and were repeated at intervals. Walking was not permitted until they showed the position well maintained and the fracture at least partly united. Roentgenographic evidence, not the calendar, determined when weight-bearing should be started and when support could be discontinued.

ANALYSIS OF SERIES

Training Injuries

Camp Carson Hospital Center.—In a series of 100 fresh fractures of the tibia reported by Lt. Col. Vernon L. Hart, MC, and his associates from Camp Carson, Colo. (*6*), all the injuries were in trainees and most of them were skiing accidents. Other causes included vehicular accidents, both military and civilian; airplane crashes; falls from horses, buildings, and ladders; and falls on icy roads and rocky terrain.

[1] In the light of results accomplished by the use of autogenous cancellous iliac bone grafts, even in the presence of infection, the use of rigid tibial grafts, with iliac bone used to fill in defects created by sliding tibial grafts, seems an extraordinarily cumbersome way to correct nonunion of long bones of the lower extremity.—M. C.

Of these 100 fractures, 78 were simple and 22 compound. Of the simple fractures, 45 were handled by closed reduction and 33 by open reduction. All the compound fractures were handled by open reduction. Bony union ensued in all 100 injuries, though in the cases handled by open reduction, the process took from 3 to 6 months.

Complications in the 78 simple fractures consisted of five instances of mild limitation of ankle motion and one each of persistent edema and ischemic paralysis of the foot. The latter complication resulted from the original injury. This patient and one other had to be separated from service.

Complications in the 22 compound fractures consisted of four instances of local infection and eight mild limitation of ankle motion. Only eight of the 22 men, however, could be returned to duty.

All of these 100 patients were admitted to the hospital for definitive treatment with fresh fractures, without infection and without soil contamination. None of them were in shock and there had been no previous surgery. The medical officers who treated the patients explained their good results on this basis.

Torney General Hospital.—The 107 fractures of the tibial shaft (exclusive of fractures involving the malleoli) treated at Torney General Hospital, Palm Springs, Calif. (7), in the 2-year period ending in August 1944 were all training injuries, incurred during the desert training program. The patients were received from station and other hospitals in southern California. Of the 107 fractures, 68 were simple and 39 compound; 65 were comminuted; and 21 were of the upper third, 40 of the middle third, and 46 of the lower third.

Treatment at hospitals near the scene of injury included closed reduction and plaster immobilization in 74 cases; debridement and skeletal traction with plaster immobilization in 18; open reduction and plate fixation in six; debridement and plate reduction in three; and debridement with wire loop fixation and with a sliding inlay bone graft in one case each. Treatment is not mentioned in the other four cases.

Management of the 42 injuries that required further treatment, and the results, were as follows:

1. Open reduction and plate fixation were performed in 10 cases. This procedure was elected in five cases because spiral oblique fractures involved the lower third of the shaft, and fractures in this location have a well-known tendency to develop shortening, as the result of overriding with delayed union because of inadequate circulation. At operation, special attention was paid to anchoring loose fragments, which were fixed by metal screws to the major tibial shaft. Comparison with nine similar injuries transferred to Torney General Hospital after treatment by open reduction and plate fixation, but without the precaution just mentioned, showed that, in two instances, further surgery would be necessary because of loose fragments.

In this group of 10 cases, bony union ensued in all within 6 to 7 months.

2. Bone grafting was carried out in 18 cases of nonunion, ranging from slight fibrous union to no union at all. Included in this group were 12 of the compound fractures treated by debridement and skeletal traction before admission, and their status

was regarded as strong evidence that skeletal distraction can play quite as important a role in nonunion as the severity of the injury.

Surgery was not undertaken for at least 3 months after drainage had ceased, even after penicillin became available. The techniques used included:

a. Sliding inlay grafts were used in four cases. The grafts were transfixed across the fracture line with two metal screws. Firm bony union was achieved in all four cases within 4 to 6 months.

b. Sliding inlay grafts with metal plate fixation were used in 11 cases, to prevent undue stress on the grafts, in the light of early observations at this hospital that, without this precaution, the grafts had a tendency to fracture and further complicate the original nonunion. Firm bony union occurred in all 11 cases within 6 to 7 months.

c. Massive onlay grafts from the opposite tibia, each fixed with four metal screws to the main tibial fragments, were used in three cases. In two cases, firm union occurred within 3 months. In the third case, slow resorption of the graft occurred, but union was attained after a sliding inlay graft and plate fixation were performed at another hospital.

3. Primary bone grafts were used in four cases, three of them fractures of the lower third of the tibia. The problems of fractures in this location have just been mentioned. In each of the three cases, a massive onlay graft, secured from the opposite tibia, was applied with two screws above and two screws below the fracture, and in each case, union occurred within 120 days. Clinically, the rate of union in these three cases was about equal to that of other groups handled with plate or screw fixation only; in each of them, however, roentgenograms showed considerably more callus formation. The fourth patient in this group, who was treated with a primary bone graft in the form of multiple bone chips, had a fracture of the middle third of the tibia and had an excellent result.

4. Ten patients showed delayed union on admission. Small amounts of callus were then present about the fracture sites, but at the end of 4 to 7 months, the fracture lines were still clearly visible. Under prolonged, continuous immobilization, union finally occurred in all 10 cases without further surgery.

Complications in this series were far fewer than expected. Fracture of the donor area of the tibia used for massive onlay grafts occurred twice. In one case, it occurred 4 months after the operation, when the patient was swimming, during reconditioning exercises. In the other, it occurred through the base of the donor area 12 days after surgery. In both instances, union of the secondary fractures was complete after 4 months of plaster immobilization.[2] There were three infections.

Combat-Incurred Injuries

Deshon General Hospital.—The more than 900 fractures of the tibia observed by Lt. Col. Reginald C. Farrow, MC, at Deshon General Hospital, Butler, Pa. (*8*), included a small number of injuries caused by training accidents or by trauma sustained while the patients were on furlough or

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[2] In three cases in this series of fractures of the tibia reported from Torney General Hospital, massive onlay grafts were taken from the tibia of the opposite side. Fracture of the donor site occurred in two of the three cases. Though this is a very small number of cases, it clearly points to the danger of leaving a patient without a leg to stand on. Iliac bone affords an abundant supply for grafting and there is yet to be recorded a fracture of the ilium following removal of bone for this purpose.—M. C.

away on passes; but, for the most part, these fractures consisted of combat injuries. They represent, as Colonel Farrow said, an average cross section of all wartime fractures of the tibia treated in a Zone of Interior hospital by average Medical Department personnel. As such, the experience is well worth recording.

Most of the patients were seen between 6 weeks and several months after injury. Most of them had compound fractures, on the way to full healing. Initial treatment had been competently carried out, and acceptable reduction had been obtained. The patients arrived in long-leg, well-padded transportation casts, which almost invariably were well applied. Pressure sores were very unusual.

Immediately on the patient's arrival at the hospital, the long-leg transportation cast was bivalved, the wound inspected, and the fracture examined clinically and by roentgenograms, as well as in comparison with previous roentgenograms if they were available. The procedure thereafter depended upon the individual status:

1. If union seemed to be progressing satisfactorily, another long-leg cast, lightly padded or skintight, was applied from the toes to the groin and the patient was allowed up on crutches, without weight-bearing. Clinical and roentgenologic evaluations of progress were made each time the cast was changed. As healing proceeded, a walking iron was added to the cast and weight-bearing was permitted. The cast was discontinued when the fracture felt solid clinically and serial roentgenograms showed an uninterrupted trend toward bony union. In most instances, gradual weight-bearing with crutches was then permitted. In a few cases, in which protection of the fracture site against lateral stresses seemed advisable, a tibial caliper brace, extending from the heel to below the knee, was applied.

Treatment by traction was not considered applicable in patients received from overseas because it carried a predictable risk of distraction and delayed union, besides the undesirable feature of further recumbency.

2. In a few fresh cases, multiple drill holes were made across the fracture site. In another small group, all simple fractures in which marked obliquity of the fracture line precluded reduction by plaster fixation, open reduction was carried out, with screw fixation. In six cases, also fresh fractures, pin fixation through each fragment was secured by external metal rods. Prompt union occurred in two cases, with good ankle and knee function. In the other four cases, union was delayed.[3]

The results in all of the cases described to this point were generally good. Interruption of knee joint function after immobilization in a long-leg plaster cast was practically always transient. Full range of motion, either spontaneously or aided by physical therapy, was possible within a

[3] This technique (Roger Anderson, Haynes, Stader) was prohibited early in 1943 and the equipment for it was withdrawn. The two good results out of six obtained in this small series are better than results in some other series.—M. C.

few weeks after removal of the cast. The reverse was true, however, of motion at the ankle, where serious, persistent stiffness was frequent. Intensive physical therapy was begun in all cases as soon as possible, but many weeks of treatment were often necessary before a range of motion approximating normal could be obtained. The explanation of the disability was not only the long duration of immobilization but the high incidence of soft-tissue injuries, with subsequent scar formation, in combat-incurred fractures.

3. Unsatisfactory alinement of the tibial fragments in a fracture progressing satisfactorily toward union was encountered occasionally, the deformity consisting of lateral, anterior, or posterior bowing. A radical change in the position of the fragments in the course of healing then had to be weighed against correction with the risk of delayed union or nonunion. When the deformity was considered great enough to warrant the risk, manual correction was accomplished under general anesthesia, through a window in the cast. Subtotal to total correction was accomplished in every case, with no interruption in the rate of healing, but in one instance, there was a temporary flareup of a quiescent osteomyelitis.

4. In another group of cases, union occurred, but loss of bony substance of various degrees left an incompletely united tibia, with diminution of the caliber of the bone of 50 percent or more at the fracture site. It was feared that, in these cases, the bone might refracture under the trauma of complete weight-bearing. The fear was augmented by the occurence of fractures in several sound tibias from which bone grafts had been secured to use for nonunion in the opposite tibia. In 10 of these fractures with bone loss, the fear of refracture was so urgent that the defect was exposed, the scar tissue removed, and the defect filled in with iliac bone chips. No refractures occurred and in every instance, roentgenograms showed the defect well filled in with the iliac bone chips. With increasing experience, fear of refractures became less, and the procedure just described was dropped, with no increase of refractures at defective fracture sites (figs. 165 and 166).

In all, including the 10 operations just described, 44 operations were carried out with autogenous bone. The other 34 operations in the series were for frank nonunion. Five of these operations were performed too recently for evaluation of results when the report was made, and seven were failures, but the remaining 22 were complete successes. Five of the failures were the result of gross infection with wound disruption.

There were eight other complications, varying from necrosis of the wound edges to purulent drainage with sinus formation. Union was achieved in all eight cases, however, and complete wound healing occurred in six, though in three instances, only after sequestrectomy and removal of screws.

The time at which a diagnosis of nonunion was made varied, with 6 months the most generally used criterion. Occasionally, the decision was

FIGURE 165.—Gunshot fractures of tibia and fibula. A and B. Lateral and anteroposterior roentgenograms of leg, showing gunshot fractures of tibia and fibula due to wound sustained on 4 November 1944. Both fractures are healed, with only slight deformity, in these roentgenograms made on 15 March 1945, a little over 4 months after injury. The tenuous healing of the tibial fracture was considered insufficient for weight-bearing. C and D. Lateral and anteroposterior roentgenograms of same leg made on 28 August 1945, about 5 months after the defect in the tibial shaft had been packed with cancellous iliac bone chips. Union of the fracture is now solid. The same metallic foreign bodies seen in figure 165A are seen in this film. (Farrow, R. C.: Fractures of the Tibia, Conservative and Operative. [Unpublished data.])

made at 4½ months. Diagnosis depended upon the presence of motion at the fracture site, roentgenologic evidence of faulty reduction, comminution or loss of bone fragments, and early sclerotic changes at the ends of the fragments.

The time at which surgery was undertaken depended upon successful skin coverage, often with one or more grafts, closure of the wound, and complete cessation of drainage over an arbitrary period of time. In 29 cases operated on for nonunion at Deshon General Hospital in which these data are available, the average interval from injury to readiness for operation was 252 days or 8.4 months. One instructive observation emerges from this small series: In 21 cases, there was precise information concerning the time between complete healing of the wound and reconstructive surgery. In the 14 cases in which no infection occurred, the period was 143

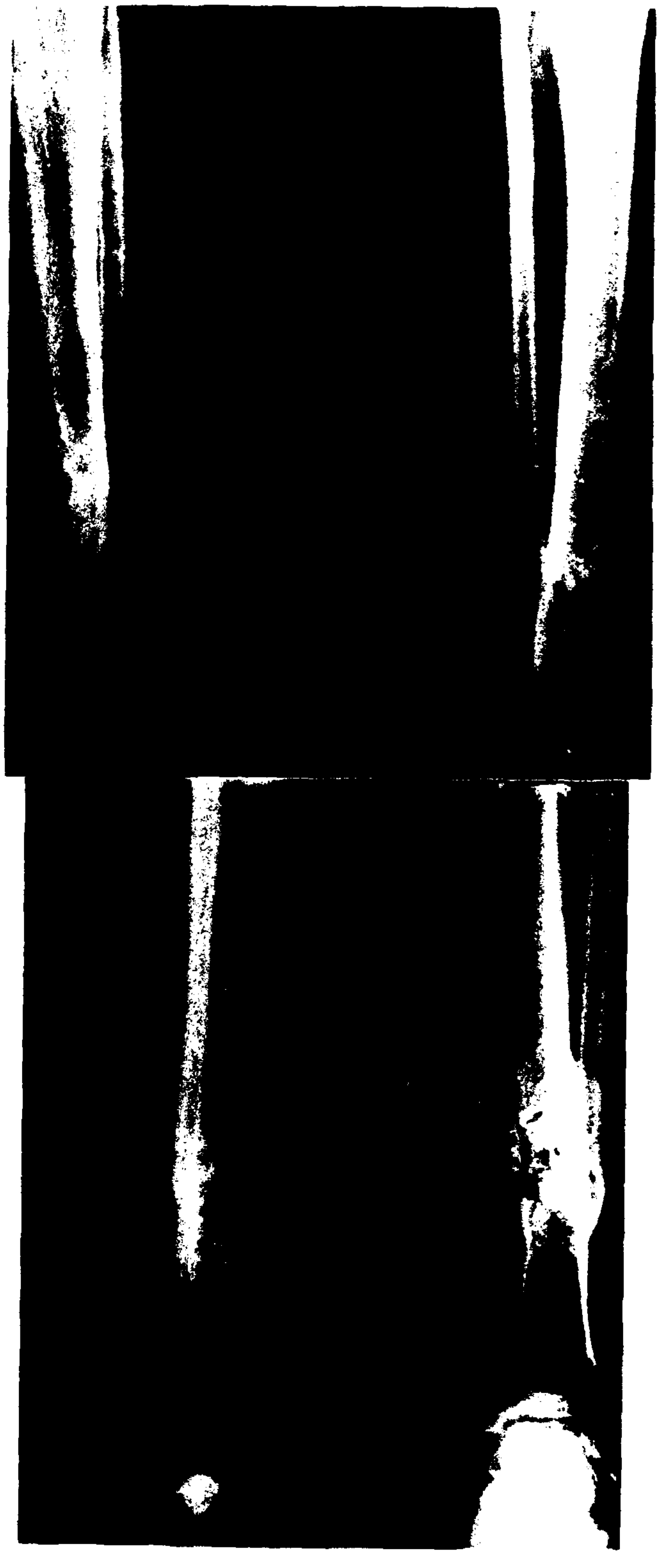

FIGURE 166.—*See opposite page for legend.*

days or 4.8 months. In the seven cases in which infection occurred, the period was 89 days or 3 months.

With the introduction of penicillin, it was expected that the time interval between wound healing and bone grafting could be decreased. The expectation was put into practice and the interval was steadily decreased until several severe infections "brought this line of thought to a sudden halt." With the realization that undue confidence had been placed in the protective power of penicillin, an arbitrary period of at least 6 months from the cessation of drainage to bone grafting was, therefore, observed in all cases. After this rule went into effect, the incidence of postoperative infection promptly fell to an acceptable level.

The technique of bone grafting employed at Deshon General Hospital was as follows:

A separate surgical team secured the needed bone graft from the medial surface of the intact tibia; the graft was about five times as long as the diameter of the bone. Scar tissue was removed completely from the fracture site, and the bone edges were freshened to bleeding. Drill holes were placed across the fracture surfaces. The bone graft was inlaid snugly, so that, in some instances, no further fixation was necessary. If such firm fixation was not possible, the graft was held in place by metal screws. Medullary bone chips were packed into the fracture site to obliterate any remaining gap.

If the fracture was in the proximal or distal third of the tibia, a sliding inlay graft was used instead of one from the opposite tibia.

If there was great instability at the fracture site because of loss of bone substance, the inlay graft was augmented by an onlay graft applied to the lateral surface and fixed by the same metal screws used to hold the inlay graft. The defect was filled with medullary bone chips, in an endeavor to restore the original caliber of the tibia.

A small tibial gap was sometimes closed by preliminary oblique osteotomy of the fibula, in the belief that the increased probability of union offset the disadvantage of a small amount of shortening.

A pressure dressing of mechanics' waste, an elastic bandage, and a light, long-leg cast were applied at the conclusion of the operation. About the 10th day the cast was bivalved, the pressure dressing was removed, and another padded long-leg plaster cast was applied. An ischial weight-bearing caliper brace was worn for several months after plaster immobilization was discontinued.

Oliver General Hospital.—Of 878 fractures of the tibia observed at

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FIGURE 166.—Nonunion of tibial fracture with management by inlay tibial bone graft across fracture site. (Top) Lateral and anteroposterior roentgenograms of tibia and fibula taken 7 months after injury and showing obvious nonunion of tibial fracture at junction of middle and lower third of shaft. The opposing tibial fracture surfaces show typical eburnated sclerotic change. The fibula is tenuously united. (Bottom) Part of anteroposterior and lateral roentgenograms of same leg, showing both fibula and tibia now firmly united after insertion of inlay tibial bone graft across fracture site. The bone graft in this instance was inlaid so snugly that no metal screws were required. (Farrow, R. C.: Fractures of the Tibia, Conservative and Operative. [Unpublished data.])

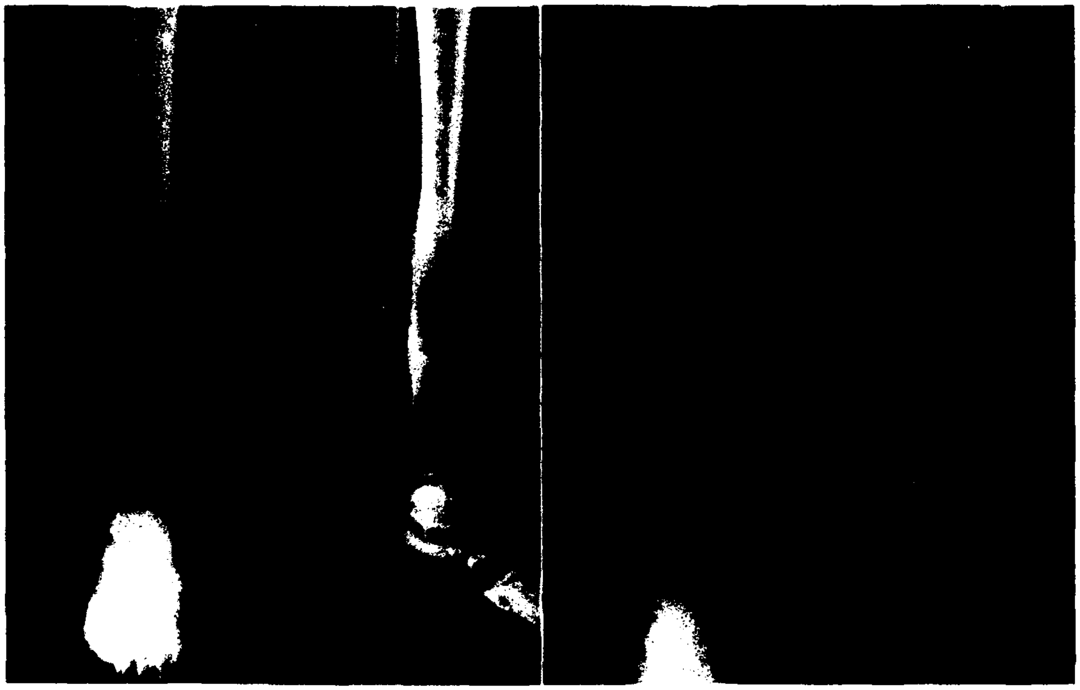

FIGURE 167.—Fracture of lower tibial shaft with bone loss. A and B. Anteroposterior and lateral roentgenograms of left leg, dated 29 November 1944, and showing fracture of lower tibial shaft with considerable loss of bone to shell wound. The fibula is intact. C and D. Anteroposterior and lateral roentgenograms of same leg, dated 23 August 1945, and showing tibial fracture united after application of a large tibial bone graft, apparently from the opposite leg. (McDowell, H. C.: Reconstruction of the Tibia. [Unpublished data.]) [This would have been an ideal case for the use of iliac cancellous bone grafts sufficient to fill the original cavity in the tibia.—M. C.]

Oliver General Hospital, Augusta, Ga., during World War II by Lt. Col. Harold C. McDowell, MC (*9*), 75 (exclusive of 31 fractures involving the internal malleolus) resulted in nonunion. The fractures were of the upper third of the tibia in seven cases, of the middle third in 27, of the lower third in 39, and of the medial tibial plateau in two. Most of these severely comminuted compound fractures had been caused by high explosives. Localized osteomyelitis was present in most of them. When the patients were received, from 8 to 12 weeks after their original injuries, most of them had large wounds which were draining profusely.

Immediate treatment consisted of complete immobilization of the leg, with changes of the cast at approximately 3-week intervals. At each change, the wound was inspected and cleansed, and penicillin was applied locally. Irrigation through windows in the cast was not permitted for fear of further contamination.

It usually required from 15 to 18 weeks for total sequestrectomy and wound healing. Immobilization was then discontinued and a brace was applied, to allow slight stress—but without weight-bearing—on the bones

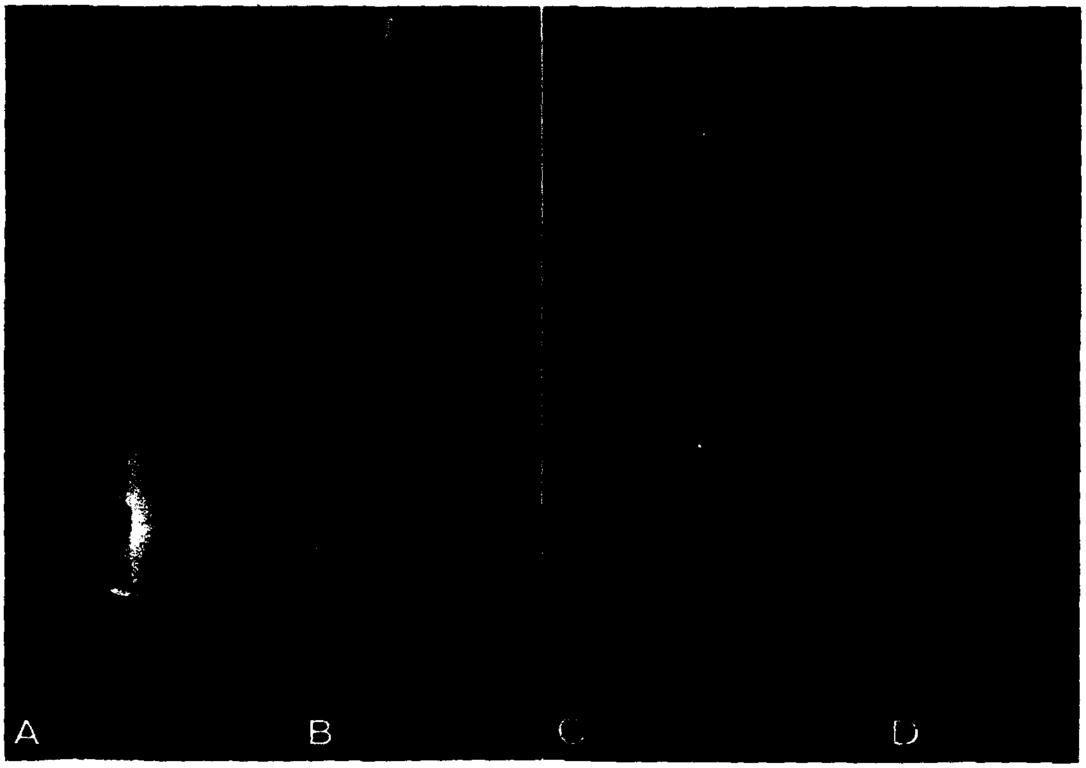

FIGURE 168.—Surgical synostosis of tibia and fibula for nonunion of tibia. A. Oblique and anteroposterior roentgenograms of left leg, dated 16 November 1944, and showing un-united fracture of tibia at junction of middle and lower third of shaft, with fracture of fibula. Bone grafts from the crest of the mid tibia have transfixed the upper and lower tibial fragments to the fibula. Before this soldier arrived at Oliver General Hospital, he had been subjected to internal fixation with plate and screws, followed by a small sliding bone graft also fixed with screws. These surgical assaults resulted in osteomyelitis with massive soft-tissue scarring. The roentgenograms reveal two broken fragments of screws. B. Oblique and anteroposterior roentgenograms of same left leg about 9 months later (6 August 1945). The cross bone grafts from tibia to fibula have increased markedly in size. The tibial fracture has united, but somewhat tenuously. (McDowell, H. C.: Reconstruction of the Tibia. [Unpublished data.])

of the ankle, tibia, and knee; to allow soft tissues to get into as good condition as possible; and to control further osteoporosis. Massage was used to loosen and toughen the skin, to allow passive motion of adjacent joints, to increase the local circulation, and to prevent further atrophy of muscles (fig. 167).

If loss of bone prevented the use of a brace, a synostosis was produced between the fibula and the fragments of the tibia (fig. 168) by passing a bone graft through the fibula into the upper fragment of tibia and another into the lower fragment. A bone graft peg was used to arthrodese the upper tibiofibular joint. One objective of this procedure was to apply more stress to the fibula, so that it would proliferate in size while

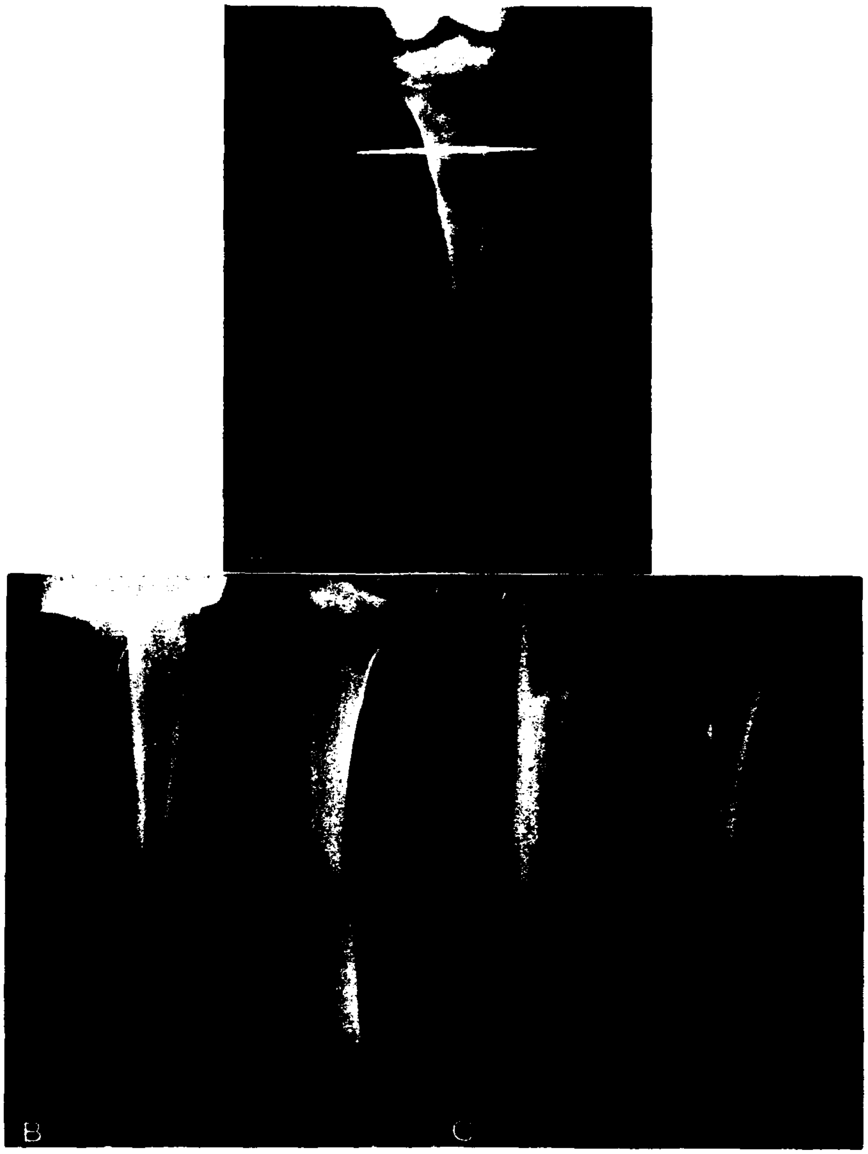

FIGURE 169.—Fracture of tibia and fibula with loss of bone substance of tibia. A. Anteroposterior roentgenogram of left leg showing fracture of tibia and fibula. The leg is in a plaster-of-paris splint with a Steinmann's pin through the upper tibial fragment. The tibia shows a loss of bone substance as the result of removal of a third fragment at the initial operation at another hospital. This nonunion should be considered iatrogenic as the fragment which would have furnished continuity and served as a bone graft was discarded by the surgeon. The removal of an intervening fragment was, unfortunately, a not infrequent surgical error. B. Oblique and anteroposterior roentgenograms of same leg after removal of plaster of paris and Steinmann's pin. Nonunion of the tibia and fibula is apparent. C. Lateral and anteroposterior roentgenograms of same leg, dated 28 June 1944, showing solid union of tibia and fibula after massive tibial bone graft had been placed across fracture site in left tibia. (McDowell, H. C.: Reconstruction of the Tibia. [Unpublished data.])

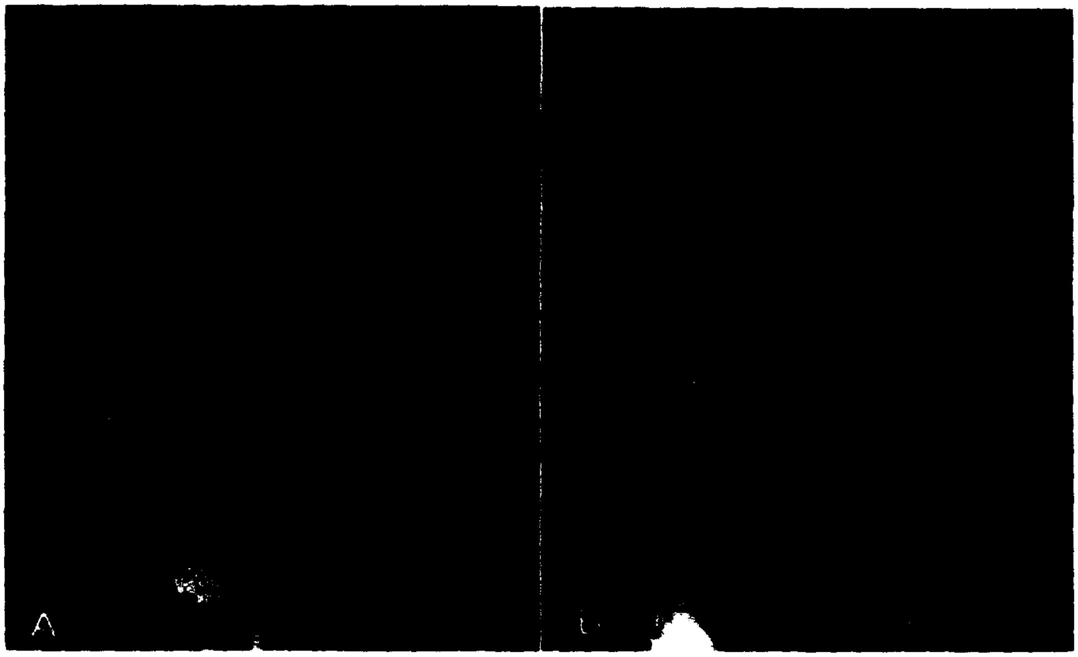

FIGURE 170.—Un-united fractures of tibia and fibula. This soldier arrived at Oliver General Hospital, Augusta, Ga., after a Roger Anderson external skeletal fixation apparatus had been applied at another hospital. A. Anteroposterior roentgenogram of left leg, dated 27 May 1943, showing fracture of mid tibial shaft and fracture of fibula near upper end. All apparatus designed for *external skeletal fixation* was recalled and their use by Army orthopedic surgeons was forbidden early in 1943. B and C. Anteroposterior and lateral roentgenograms of same leg, showing healed fracture of tibia after sliding graft from same tibia was applied across fracture site. The healed fibular fracture is now more apparent. This corporal returned to full duty and served overseas with an Armored Division. (McDowell, H. C.: Reconstruction of the Tibia. [Unpublished data.])

the patient was wearing a brace. If the operation was successful, some weight would be transferred later from the tibial bone graft to the fibula.

Before bone grafting was undertaken, all scars were excised or, if they were too large for simple excision, they were resected and the affected area was covered by full-thickness pedicle grafts from the opposite leg. The brace gave sufficient support to the tibial fragments to permit plastic procedures on the soft tissues.

The single failure in the 40 bone grafts that had been performed in the 75 nonunions when this report was made was caused by the slough of a small scar over the graft, which was lost when osteomyelitis developed. In the remaining 35 cases, all patients had undergone sequestrectomy and their osteomyelitis was under control when this report was made. Most of them were merely waiting for the lapse of sufficient time to make definitive surgery safe.

At preliminary surgery, loose sequestra were removed without disturbing surrounding fibrous tissue any more than was absolutely neces-

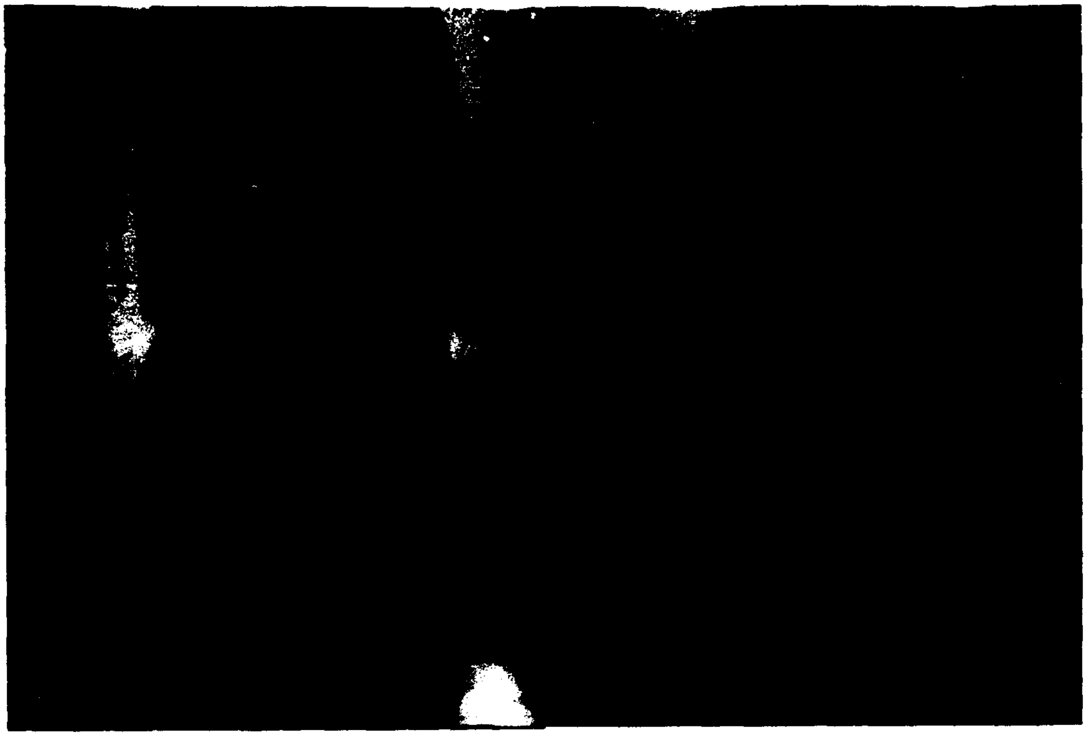

FIGURE 171.—Unreduced compound comminuted fractures of tibia and fibula. A. Lateral and anteroposterior roentgenograms of unreduced compound comminuted fractures of right tibia and fibula, dated 28 September 1943. B. Anteroposterior and lateral roentgenograms of same leg, dated 10 March 1944, showing solid bony union of both tibia and fibula following inlay bone graft to tibia. This soldier returned to full duty and served overseas with an Armored Division. (McDowell, H.C.: Reconstruction of the Tibia. [Unpublished data.])

sary. Curettage was used only when it could not be avoided. Sinus tracts were opened by longitudinal incision and traced to their termination. Wound edges were undermined and blunt dissection and sutured loosely with silkworm gut. The wound was packed only if the edges could not be brought together. A No. 16 rubber catheter was inserted into the upper angle of the wound, so that drainage would be facilitated when the leg was elevated. It was usually removed in 72 hours; while it was in situ, penicillin solution was instilled daily. Otherwise, the usual postoperative routine was followed until wound healing was complete and definitive surgery could be performed.

Massive inlay bone grafts were used routinely at Oliver General Hospital. They were secured from the injured leg when the fracture was in the lower third of the shaft or, in certain selected cases, in the middle third. In all fractures of the upper third, or when an extremely long graft was needed in fractures of the middle third, the graft was obtained from the opposite leg (figs. 169–171).

The following techniques, which do not include internal fixation, were used:

1. Lower third of shaft. A sliding graft was never employed in this area because the exact fit, which is essential, was better secured with a transplantation graft from the opposite tibia. Straight incisions which passed directly over the graft were avoided; they were prone to separate, and, if even a slight stitch infection developed, a sinus tract would lead directly to the graft. Instead, a medially curved incision, 6 to 8 inches in length, was used unless a lateral curvature was necessary to avoid a large scarred area.

The graft was obtained from the upper third of the affected tibia, through an incision that curved in the opposite direction from the lower incision. An island of normal skin, 1 to 2 inches wide, was left between the two incisions.

A gutter for the reception of the inlay graft was formed across the fracture site by the twin Albee saw. The length of the graft depended upon the amount of sclerosis about the fracture site. It was a cardinal surgical principle, especially in longstanding injuries with much eburnation of bone, that the graft must completely bridge the sclerotic areas of both fragments connecting the normal marrow cavity above and below the fracture site. Grafts were usually at least 6 inches long.

A small island of bone corresponding to the island of skin between the curved incisions was left undisturbed between the gutter made across the fracture site and the gutter resulting from removal of the graft from the upper third of the tibia. This was done for several reasons: It eliminated the need for internal fixation. It allowed the graft to be moist under the bridge of bone at the upper extremity of the gutter. Finally, if an infection did develop in one incision, the bone would inhibit the spread of the infection to the other incision.

After the bone between the saw cuts across the fracture site was removed with an osteotome, the eburnated bone at the fracture site was removed deeply. The twin saws were then set to allow for the width of two saws before removal of the graft from the upper third of the tibia, to provide the accurate fit required for the graft. The graft itself was always an inch longer than the gutter across the fracture site, so that it could be mortised under each end of the gutter.

2. Middle third of shaft. The technique just described was used for nonunions low in the middle third of the shaft if a graft of sufficient length could be obtained from the damaged tibia. The crest of the tibia was never used for this purpose. When it was necessary, as it usually was, to use the opposite tibia, a curved longitudinal incision, 8 to 10 inches long, was made over the fracture site, and a deep gutter was cut across it, extending into each fragment sufficiently to make contact with normal bone marrow. The graft, about three-fourths of an inch wide, was then

obtained from the upper third of the tibia and mortised across the fracture site as in the technique just described.

3. Upper third of shaft. Massive inlay grafts were used to bridge all defects of the upper third of the shaft. A curved longitudinal incision was used, and the graft was obtained from the upper third of the opposite tibia. It must fit the host substance accurately and must extend into each fragment for an adequate distance.

After each of the operations described, the extremity was completely immobilized in a long-leg cast extending from the base of the toes to well up on the upper thigh; the knee was put up in not more than 5-degree flexion unless there was some special reason to exceed this level. The leg was kept elevated for 4 weeks. Serial roentgenograms were made, but the cast was not disturbed for at least 12 weeks. In a few cases, union was considered complete at this time, by clinical and roentgenographic evidence, but in most instances, it was not complete and the same type of cast was applied for another 6 to 8 weeks. Then, a fitted brace was applied, and weight-bearing with crutches was begun.[4]

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[4] While this report from Oliver General Hospital shows excellent results in the treatment of un-united fractures of the tibial shaft, iliac cancellous bone could have been used in some instances to great advantage.—M. C.

CHAPTER XXV

Injuries of the Ankle

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

GENERAL CONSIDERATIONS

Since the ankle takes the full body weight with every step a person takes, as well as half of it when he is simply standing, it is surprising that so little has been written about the ankle as compared with other joints (*1*). Early in the war, the unfortunate civilian tendency of diagnosing a sprain without roentgenographic exclusion of a fracture was carried over into military practice, and disability and manpower losses were compounded by the error. There was notable improvement in this respect as time passed. Eventually, the policy was general of suspecting a fracture in all such injuries and investigating them roentgenologically as well as clinically. A fracture that was incorrectly treated as a sprain was often more serious than it would have been if it had been recognized and properly treated at once.

SPRAINS

Sprains of the ankle were so frequent in the Zone of Interior in World War II that no precise statistics exist for them. Many of them were training injuries. Others were the results of walking on uneven surfaces, jumping, falling, and other accidents.

Diagnosis

Clinically, a detailed examination of the injured ankle was made to detect localized swelling and tenderness over the ligaments and the bony points at which fractures are likely to occur.

Roentgenograms were made in all correctly managed injuries about the ankle associated with pain, swelling, and disability. Fluoroscopy was not used. Projections were made in the anteroposterior position, with the malleoli equidistant from the film, and in the lateral position, with the median or medial malleolus next to the film, depending upon the location of the suspected injury. If these views were not diagnostic, oblique views were taken. Many medical officers strongly advised, in all such injuries, anteroposterior radiography with the foot in inversion, with or without a previous injection of Novocain (procaine hydrochloride). There was al-

ways the possibility, in badly sprained ankles, that the tibia and the astragalus had separated, and roentgenologic demonstration of such a separation pointed to a ligamentous rupture.

Management

For mild sprains of the ankle, Novocain injection of the tender areas, with immediate weight-bearing, was reported as highly effective and very popular in some hospitals and as equally unpopular in others. At one of the Army Air Forces 1943 conferences (*2*), one demonstration concerned treatment of severe sprains of the ankle by the application of a skintight plaster splint, similar to the Delbet walking plaster, extending from below the knee to the plantar aspect of the heel. When this method was used in combination with early weight-bearing, it was supposed to achieve unusually early return to normal activity.

The management in the Army of even simple sprains of the ankle was more complicated than in civilian life because it required hospitalization. The office treatment possible in similar circumstances in civilian life was not possible in the Army. On the other hand, the military patient was under complete control. He had to stay in bed, or he had to be out of bed, or he had to move his foot and ankle as directed. The manpower losses were, therefore, less than they might otherwise have been.

INJURIES OF THE LATERAL LIGAMENTS

Significant displacement of the astragalus at the ankle mortise was diagnostic of a complete tear.

Treatment for ruptures of the lateral ligaments was plaster immobilization for 8 weeks. Any other method left the patient with a weak ankle, with a tendency to recurrent luxations of the talus on a slight inversion strain. In complete ruptures, it was sometimes wise to consider suture of the tear. Simple suture was the usual technique, but at one of the 1943 Army Air Forces conferences (*2*), the use of a tendon of the peroneus brevis muscle to effect the repair was reported.

DISLOCATIONS

Simple dislocations of the ankle were not common. The pathologic process frequently included a severe ligamentous tear, and the correct procedure was repair of the tear, to prevent chronic subluxation or dislocation. Severe arthritic changes often followed even correct management, and fusion was required because of continued disability.

Fracture-dislocations are discussed later in this chapter.

FRACTURES

General Considerations

It was estimated that 95 percent of all fractures of the ankle were of the external-rotation, abduction, and adduction types. The remaining 5 percent were of the compression type or were atypical.

As early treatment as possible was desirable in all fractures of the ankle. In fact, what was done for them during the first 24 hours largely determined the duration of disability and often determined the end result. Early, accurate reduction, preferably before swelling set in, was far more effective than the later application of a cast, which tended to become loose and lose its supporting properties after swelling had subsided. Early reduction also meant that bleb formation would be eliminated altogether, or at least would be minimal.

By World War II, padded casts and the use of large amounts of sheet wadding were no longer considered necessary in many types of ankle fractures. No padding was necessary over the shinbone, and if weight-bearing was not a part of the immediate treatment, pads were not needed over the lateral and medial malleoli; they were used, however, if walking casts were to be used. The preferred technique was to apply two rolls of plaster circular fashion, then apply anterior and posterior splints and hold them together with another circular roll of plaster. If the cast became too snug, it could be split on one side and brought together again after swelling had subsided. The toes were examined, to determine the status of the circulation, at least every 2 hours for the first 24 hours.

Fractures of the tibia extending into the ankle joint called for as nearly perfect anatomic reduction as possible. If reduction was not precise, traumatic arthritis might develop subsequently and be associated with pain and disability of such magnitude as to justify fusion of the ankle joint. Reduction was usually accomplished under general anesthesia by the closed technique. If the attempt was not successful, surgical reduction was carried out, with internal fixation. A well-fitted plaster cast was applied after surgery.

Severely comminuted fractures of the ankle were frequently followed by good anatomic results with rest in bed, the use of the Thomas splint, and balanced suspension skeletal traction through the os calcis (*3*). The Thomas splint was used much more frequently in military practice than in civilian life, partly because it was The Surgeon General's preference and partly because, in the Army, prolonged hospitalization is not the financial problem it is in civilian life. Residual stiffness was fairly frequent after traction was discontinued, but fusion was seldom necessary.

Undisplaced Fractures

Before World War II, it had been observed by many orthopedic surgeons in civilian practice that undisplaced or slightly displaced fractures of the ankle, in which manipulation was not necessary, returned to full function most promptly if the injured part was protected from trauma but was not immobilized. Perhaps the most striking example of the application of this policy in military practice was the excellent results achieved in march fractures at Fort Jackson, S.C. (*4*), and elsewhere.

The method was not generally accepted, and it was not easy to have it used: By instinct and training, most medical officers assigned to orthopedic sections considered the bony components of the ankle joint an area in which rigid immobilization was demanded when its integrity was violated by a fracture, regardless of whether or not displacement was part of the picture. To them, fixation by plaster was the way fractures should be treated.

During 1942 and 1943, the management of undisplaced fractures of the ankle that did not require manipulation was radically altered at the Fort Jackson Station Hospital (*4*). After the security of the ankle joint was established beyond doubt by anteroposterior, lateral, and oblique projections, rigid immobilization was discarded in favor of bed rest, elevation of the parts, and icepacks. During this period, non-weight-bearing motion was encouraged, and supplemental hydrotherapy, massage, and gentle manipulation were instituted. In other words, treatment of the bony lesion was subordinated to treatment of soft-tissue damage. Weight-bearing was permitted as soon as soft-tissue damage was under control.

Four considerations were important in this change of management:

1. The most frequent bony injury about the ankle involved the distal fourth of the fibula, at the external malleolus or slightly above it in the fibular shaft.
2. Many patients, by the aid of walking devices attached to, or incorporated in, their casts, could have partial use of their extremities during the period of immobilization.
3. The convalescent (out-of-plaster) period was frequently longer than the period of immobilization because it was characterized by persistent swelling on dependency, pain on weight-bearing with crutches, and limitation of motion.
4. A most important consideration in the new routine was the complete control that could be exercised over patients in military circumstances.

The clinical impression of the orthopedic surgeons at Fort Jackson that patients with fractures of the ankle treated without immobilization recovered more rapidly than those who were immobilized was confirmed by a comparative survey of 64 patients, 32 treated by plaster immobilization and 32 by the new regimen just described. The cases were consecutive and were unselected except that the pattern of injury was similar by clinical and roentgenologic evidence. All the patients had the same treatment in the convalescent phase, first physical therapy and then physical therapy plus convalescent drill, which was utilized at Fork Jackson long

before it became required routine. It was thought to be the most effective measure available for soft-tissue rehabilitation, and also to furnish the best test of fitness for duty. All patients were reviewed at daily staff conferences before their discharge from the hospital.

The comparison of the two series of cases was based on a single factor, the number of hospital days (that is, the time lost from duty) necessary for complete rehabilitation. The average period of hospitalization for the patients treated by immobilization was 57.3 days, against 35.7 days for the patients treated without immobilization. Examination of the files of the reclassification board revealed no reclassification to limited service of any of these patients.

On the surface, this new method gave better results than the former practice of immobilization in that it permitted earlier return to duty (saving of hospital days) by some 3 weeks, on the average, during the important training period.

Fractures of the Malleoli

Injuries of the lateral malleolus.—Fractures of the lateral malleolus were very frequent. In one series of 100 fractures of the leg and ankle reported at the 1943 Army Air Forces conferences (*2*), 95 involved the ankle, and 82 of the 95 involved the lateral malleolus.

If the fracture line took the usual direction (oblique from behind, downward, and forward), immobilization was not always necessary, and many believed that results were far better, and were attained more quickly, if it was omitted. The involved area was injected with Novocain and was supported by strong adhesive strapping, after which weight-bearing was permitted at once. Other orthopedic surgeons accepted this method with reservations, specifying that it should be used only if the fracture was below the attachment of the tibiofibular ligament. They considered immobilization in plaster necessary if the fracture extended up into the area of attachment. Still another group of orthopedic surgeons preferred to elevate the extremity until swelling had subsided, then strap the ankle in a neutral position and permit the patient to be ambulatory in a shoe.

In contrast to many injuries about the ankle, patients with injuries of the lateral malleoli usually did well and could be returned to full duty.

Injuries of the medial malleolus.—Fractures of the medial malleolus were usually accompanied by fractures of the fibula. Reduction often appeared excellent clinically and in roentgenograms, but nonunion was found in a fair number of cases because ligamentous fibers or bits of periosteum were caught between the fragments of tibia. As a result, many men were left with painful ankles, and there was a considerable loss of manpower. As the war progressed, therefore, the tendency was more and more to resort to open reduction, either immediately or as soon as it be-

came evident that conservative measures would not be successful. By the end of the war, open reduction was the general policy if absolute hairline reduction was not evidenced by roentgenograms.

In displaced fractures, especially those in which the fragments were rotated, it was also the policy to fix the malleolus to the tibia by nail, screw, or even bone graft.

Immediate weight-bearing was contraindicated in fractures of the medial malleolus; walking casts were found to play a definite part in the incidence of nonunion.

Results improved when open reduction became the policy, but the ultimate prognosis was always guarded after it was found that traumatic arthritis could develop from 1 to 3 years after injury. During the war, a considerable number of patients with excellent immediate functional results had to be separated from service later for this reason.

In 878 fractures of the tibia admitted to the orthopedic section of Oliver General Hospital, Augusta, Ga., between 26 January 1943 and 1 October 1945, there were 94 nonunions, 31 of which were of the medial malleolus (*5*). All of these 31 cases were managed by bone grafts, applied by one or the other of the following techniques:

1. An inlay bone graft peg was applied through a curved longitudinal incision, about 3 inches long, over the medial malleolus, with exposure of the fracture site by blunt dissection. All fibrous tissue between the fragments was excised, and each fragment was roughened with an osteotome and mortised for accurate fitting. While the lower fragment was held in the correct position, a hole was drilled through it obliquely, beginning at the tip and extending across the fracture site and into the lower third of the tibia. With the drill left in place to maintain position, a second incision was made over the upper third of the crest of the tibia. A graft about 2½ inches long by three-eighths of an inch in diameter was taken from the anterior lateral crest of the tibia and run through the Albee bone mill to produce a No. 2 bone peg. The drill was then removed and the bone peg driven firmly into place (fig. 172). A cast was applied from the base of the toes to the tibial tubercle.

2. A sliding (inlay) bone graft was applied through the incision just described, but about an inch longer. The steps of the operation were the same until after the ends of each fragment had been mortised. Then, saw cuts about one-half of an inch apart were made with the twin Albee saw set as near as possible to the tip of the lower fragment, across the fracture site, and into the lower third of the tibia for about 2½ inches. The bone between the saw cuts was removed. The portion from the lower fragment was discarded, and the graft obtained from the lower third of the tibia was slid down across the fracture site. A better fit was usually obtained if the graft was reversed before it was inserted. Internal fixation was not required in any instance in this series. Postoperative immobilization was carried out as in the technique first described.

A walker was attached to the cast 4 weeks after operation. The cast was removed and weight-bearing begun after 8 weeks. Union was usually firm at the end of 12 weeks. In 30 of the 31 cases treated by these techniques (the other case was too recent for evaluation when the report was made), union was firm and the fracture site was obliterated at the end of 12 weeks, and recovery was complete at the end of 4 months.

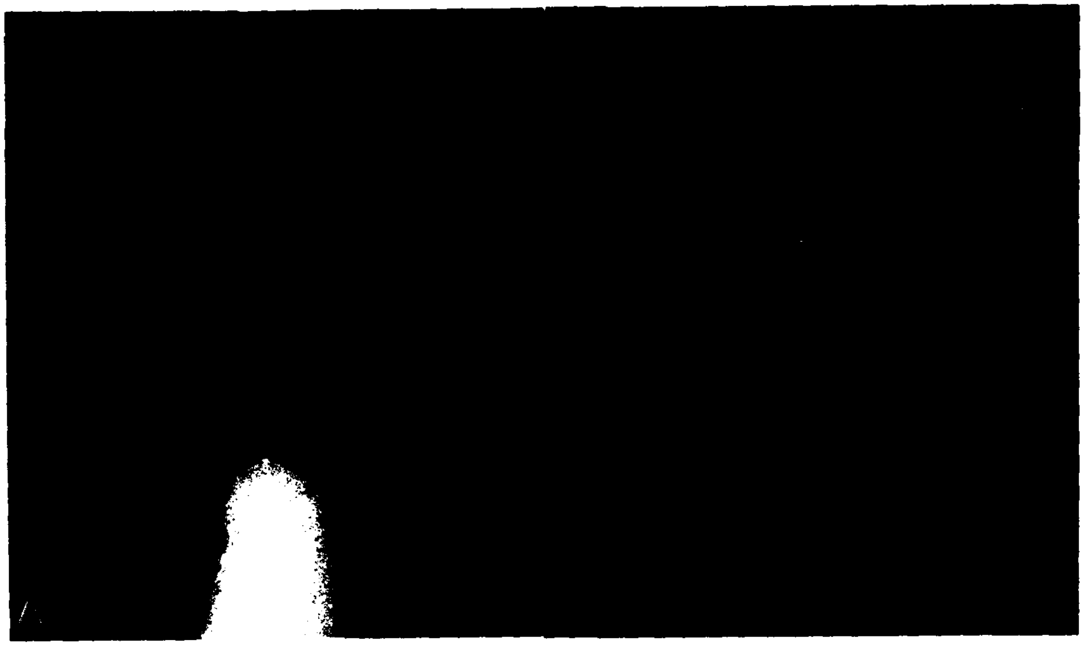

FIGURE 172.—Bone graft in fracture of medial malleolus. A. Anteroposterior roentgenogram of ankle joint showing un-united and displaced fracture of medial malleolus. B and C. Anteroposterior and lateral roentgenograms of same ankle and leg 5½ months later, showing medial malleolus firmly united to tibia with bone graft evident. The donor site at the mid tibial crest is also apparent. (McDowell, H. C.: Reconstruction of the Tibia. [Unpublished data.])

Injuries of the posterior malleolus.—Injuries of the so-called posterior malleolus (injuries of the posterior lip of the inferior articular surface of the tibia) were managed according to the extent of the damage:

1. If less than quarter of the articular surface was involved, a residual upward displacement caused little concern.
2. If sufficient smooth joint surface remained intact, the small fragment was displaced out of the way, and no tendency was observed for the astragalus to displace posteriorly.
3. If the fragment comprised as much as a third of the articular surface, anatomic reduction was necessary.
4. If closed techniques failed, and particularly if large fragments were displaced, accurate reduction was essential, with fixation into the tibia by screws or nails. As the war progressed, there was, again, an increasing tendency to resort promptly to open reduction.

Trimalleolar fractures.—Trimalleolar fractures were usually associated with complete or partial dislocation of the ankle. Roentgenograms were often confusing. When the anterior or posterior lip of the tibia was fractured, reduction might seem perfect in the anteroposterior view while the lateral view would show the lip both tilted and compressed. In these circumstances, the degree of possible dorsal or plantar flexion was decreased, depending upon which lip was involved, and the opportunities for

the development of traumatic arthritis were increased. Surgery was not very successful, and patients were seldom able to perform full duty.

Fracture-Dislocations

Fracture-dislocations of the ankle were not always regarded as emergencies, but they always should have been. Unless prompt reduction of the dislocation was carried out, necrosis of the overlying skin was a possibility, with conversion of the injury to a compound fracture and the consequent risk of serious infection. Also, the displaced body of the astragalus might produce serious pressure on the posterior tibial vessels, with the consequent risk of gangrene, while the vascular deficiency caused by direct pressure and swelling introduced the risk of Volkmann's ischemia. The longer the dislocation was permitted to exist, the more difficult was the reduction.

The correct procedure in these cases was immediate manipulative reduction of the dislocation, sometimes supplemented by traction on the os calcis with a Kirschner wire. If the attempt at closed reduction was not promptly successful, open reduction was done immediately. The objective was to reduce the risk of vascular necrosis of the astragalus to a minimum. If the results were poor, astragalectomy or arthrodesis could be done later. In some of these injuries in which reduction seemed perfect, results were unsatisfactory because of infection of the articular cartilages or because of arthritic changes.

DIASTASIS OF THE DISTAL TIBIOFIBULAR JOINT

Before World War II, the orthopedic literature tended to confuse the picture of diastasis of the distal tibiofibular joint by concentrating on the associated fracture and ignoring the diastasis (*6*). This was unfortunate. If the diastasis was promptly diagnosed and properly treated, the ultimate disability was not great. If the correct diagnosis was not made, and if, as often happened, the condition was assumed to be a simple sprain, the patient was left with a painful ankle and considerable degree of disability.

Diastasis of the tibiofibular joint was the result of external rotation or abduction injuries at the ankle, with extensive ligamentous rupture. It could occur without associated fractures, but was most often seen with Pott's fracture.

The symptoms and signs of the associated fractures often confused the diagnosis by overshadowing those of tibiofibular rupture and diastasis. Swelling and tenderness over the distal tibiofibular joint were useful signs when the fibular fracture was fairly high, but they were of no value when the lateral malleolus was fractured. Gross ballottement of the fibula was occasionally elicited. Widening of the malleoli and abnormal anterior

and posterior motions of the fibula were present when the ligaments were extensively torn.

Roentgenograms were preferably made under local anesthesia, with the orthopedic surgeon present to supervise the positioning. Fluoroscopic examination was discouraged. Projections included:

1. Anteroposterior, with the malleoli equidistant from the film and the foot in plantar flexion.
2. Same, with the foot in dorsiflexion.
3. Same, with the foot rotated laterally.
4. Lateral, with the foot in neutral position.

Medical officers who interpreted the films made in such injuries had to have a thorough understanding of their mechanism. The ligamentous injury was as important as the bone injury.

Gross diastasis could often be demonstrated in the standard anteroposterior and lateral films; if it could be, no other projections were necessary. Positive diagnostic signs included:

1. The presence of an isolated fragment of bone between the distal tibia and fibula, resulting from ligamentous avulsion of the lateral border of the tibia.
2. A fracture 2 to 3 inches above the lower tip of the fibula associated with a fracture of the internal medial malleolus or a rupture of the medial lateral ligament.
3. Widening of the space between the internal medial malleolus and the internal aspect of the astragalus when the fibular fracture was fairly high and the internal medial malleolus was not fractured. These findings indicated not only tibiofibular diastasis but also rupture of the internal medial lateral ligament.
4. Lateral displacement of the astragalus, which frequently, though not always, was the result of diastasis. Normally, the external border of the astragalus is in line with the external line of the tibia.
5. Loss of parallelism of the joint lines between the lower tibia and the superior border of the astragalus. This loss might also be caused by fracture of the medial or lateral malleolus or rupture of the medial or lateral ligament.
6. Gross diastasis of the mortise, with evident widening between the tibia and the fibula.
7. Complete diastasis with interposition of the talus. This observation was most unusual and was present only when the ligaments and interosseous membrane were completely torn.

In doubtful cases, comparison of the injured and uninjured ankles was often useful. When this comparison was made, however, it had to be remembered that, when the foot is dorsiflexed, there is a normal amount of widening between the tibia and the fibula; anteroposterior films of a normal ankle show a widening on dorsiflexion of at least 2 to 3 millimeters.

If the diagnosis was not recognized as such and the injury promptly treated, widening of the mortise resulted, as well as anteroposterior instability of the distal and end of the fibula. If normal movement and joint stability were to be preserved, reduction must be carried out promptly and accurately, and must be maintained until the ligaments and the associated fractures had healed. The best method of treatment was manipulative reduction and the application of a cast, which must fit snugly, to

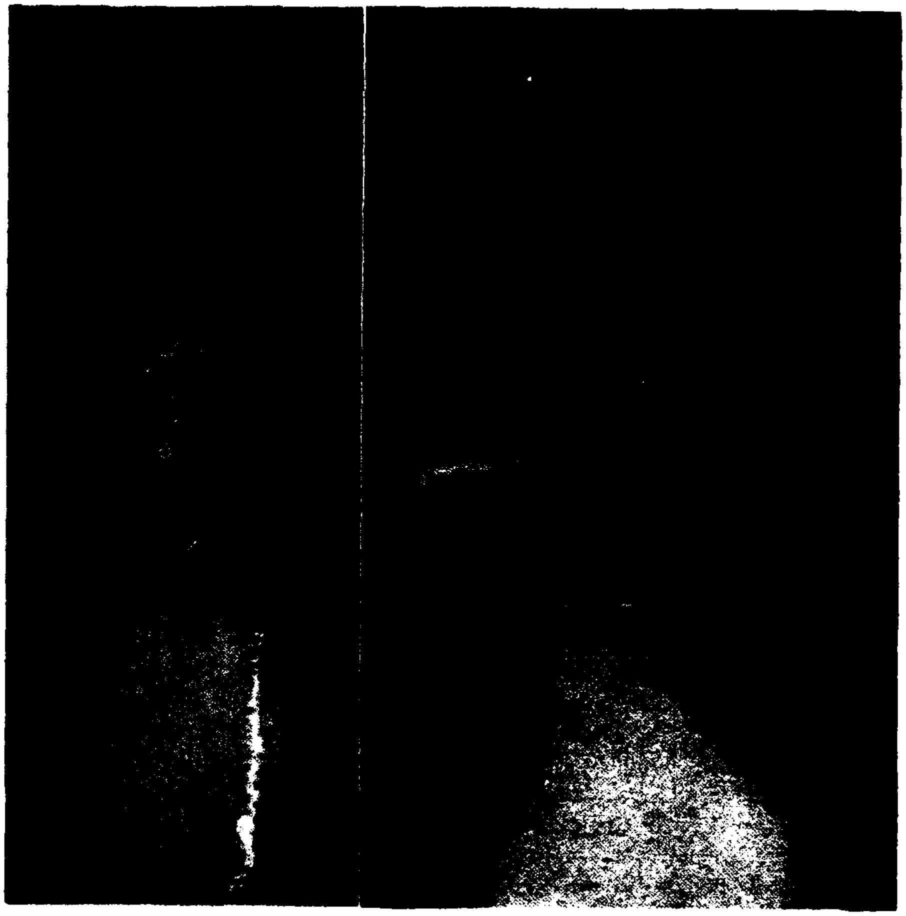

FIGURE 173.—Un-united fracture of fibula, with diastasis of tibiofibular joint. (Left) Anteroposterior roentgenogram of ankle, showing fracture of lower shaft of fibula extending into tibiofibular joint, with obvious diastasis of that joint as shown by lateral displacement of astragalus. (Right) Anteroposterior roentgenogram of same ankle, with diastasis reduced and astragalus snugly in mortise between medial and lateral malleoli. The fibula and tibia are transfixed with bolt with nut and washer. (Snedecor, S. T.: J. Bone & Joint Surg. 28: 332-342, April 1946.)

prevent recurrent displacement, and must be kept in place, as a rule, for 10 weeks.

If there was difficulty in reapproximating the tibia and fibula, the usual cause was the interposition between the tibia and the fibula of bone or other structural material or sometimes, in patients seen late, of organized clot. The correct procedure in such cases was immediate removal of the obstructing substance through a short incision over the anterior aspect of the tibiofibular joint. If there was difficulty in holding the tibia and fibula together after its removal, a screw or wire could be inserted through a small incision on the lateral aspect of the fibula. If the separation was

gross, a transverse screw could be used. The metal was removed as soon as the ruptured ligaments had healed and the fracture was firmly united. Failure to remove it resulted in loss of dorsiflexion, since motions of the fibula are impossible when it is fixed to the tibia (fig. 173).

Postoperative positioning was important, whether or not internal fixation had been used. The position of choice was slight plantar flexion, to eliminate any tendency for separation of the bones, and in accord with the physiologic observation that separation of the mortise after the ligaments are divided takes place when, on dorsiflexion, the foot reaches 90 degrees. This fact was particularly important in instances of posterior marginal fractures of the tibia, in which the usual fixation in dorsiflexion could cause separation of the tibia and fibula.

No weight-bearing was permitted in diastases for at least 3 weeks, after which standard weight-bearing was allowed. Patients who were thus treated had less pain and swelling, and less restriction of early motion, than those managed by long immobilization in casts.

ARTHRODESIS

As has been intimated several times earlier in this chapter, pain and disability of the ankle joint were often of such magnitude after injury as to justify arthrodesis, which was not undertaken, however, until the necessity for it was established by a sufficient period of observation. In occasional cases, pain ceased and function improved, and in other cases, spontaneous fusion occurred. Severely comminuted fractures of the lower end of the tibia, particularly when they were associated with fractures of the astragalus, were an exception to this generalization; they required early fusion to put them in the desired position for ankylosis. Arthrodesis was required more often in combat-incurred injuries than in injuries incurred in other circumstances (figs. 174 and 175).

Triple arthrodesis was performed in 82 cases, most of them compound war injuries, at Fletcher General Hospital, Cambridge, Ohio, during the year ending on 1 November 1945 (*7*). Operation was not undertaken until drainage had ceased for an acceptable period of time and until there had been a trial of unprotected walking for 1 or 2 months.

The injuries involved the calcaneus, proximal tarsal bones and joint surfaces, talus, cuboid, and navicular bones and were complicated by traumatic subtalar arthritis.

Immobilization was accomplished by a long-leg plaster cast, with the heel in neutral or slight valgus position, the ankle at 90-degree dorsiflexion, and the knee in complete extension, a position found more conducive to the prompt disappearance of edema than immobilization in a position of flexion. The position of the heel was found to be less important than it had previously been considered. The neutral position produced a better gait than the valgus position. The varus position gave a poor gait.

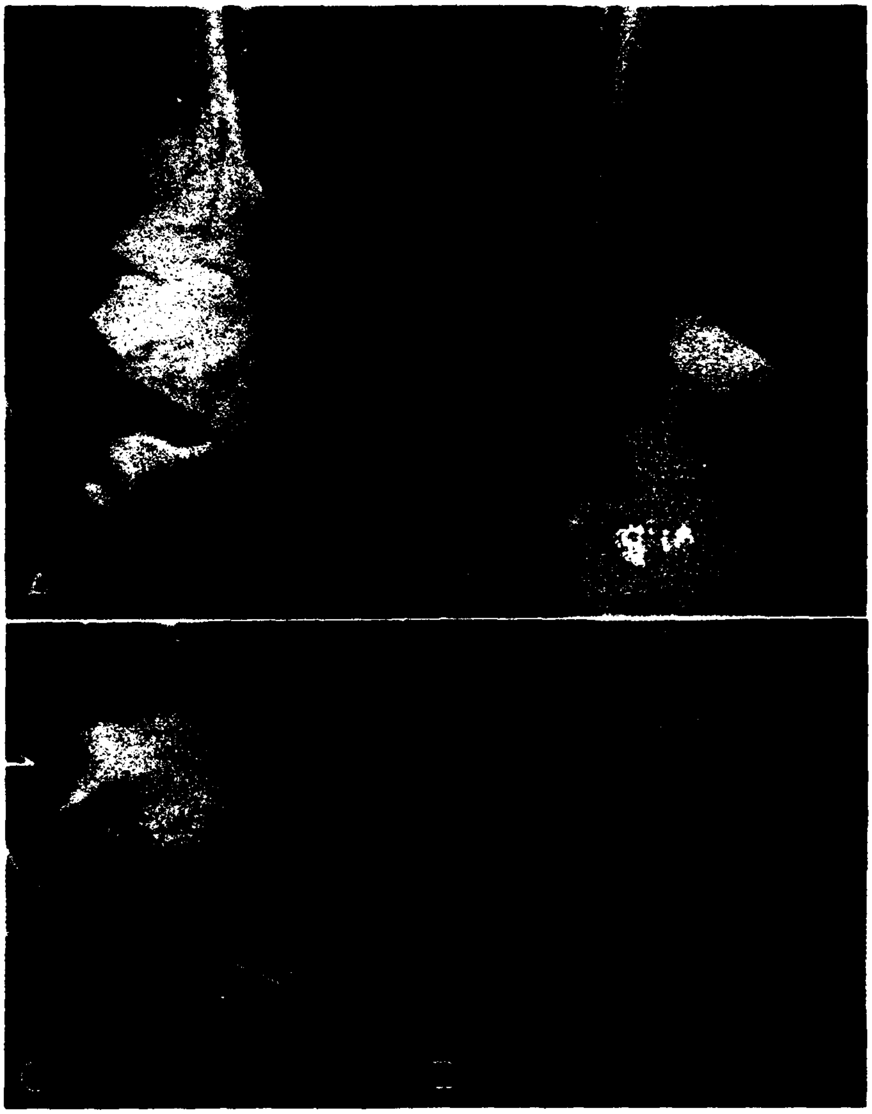

FIGURE 174.—Combat-incurred gunshot fracture of medial malleolus. A and B. Lateral and anteroposterior roentgenograms of rear foot and ankle of soldier who sustained a shell wound in Tunisia. The fracture of the medial malleolus, the somewhat irregular joint surface at the ankle, and the large metallic fragment in the body of the astragalus are all evident. C. Lateral roentgenogram of same ankle after removal of shell fragment. The ankle joint space is barely visible, and there is sclerosis of both tibia and astragalus. D. Lateral roentgenogram of same ankle after persistent pain made mandatory surgical arthrodesis, shown here, which was highly successful. (Snedecor, S. T.: J. Bone & Joint Surg. 28: 332-342, April 1946.)

FIGURE 175.—Landmine fractures of medial malleolus, talus, and os calcis. (Top) Anteroposterior and lateral roentgenograms of ankle and rear foot showing fractures of medial malleolus, talus, and os calcis, with marked distortion of ankle and subtalar joints. This wound—an example of combined foot and ankle injury—was sustained by a mine explosion while the patient was riding in a jeep. (Bottom) Anteroposterior and lateral roentgenograms of same ankle and foot in circular plaster of paris after surgical arthrodesis by sliding graft from tibia driven into talus. (Snedecor, S. T.: J. Bone & Joint Surg. 28: 332–342, April 1946.)

As soon as the cast was applied, it was split throughout its length and the limb was elevated. Two weeks later, an unpadded long-leg cast was applied; the alinement of the heel was corrected without anesthesia. When the cast was changed, the patient was allowed up on crutches, without weight-bearing, which was not permitted until 6 weeks after operation. Then, an unpadded walking boot was applied and was used, preferably without external support (crutches were strictly prohibited), for another 6 weeks. Active walking exercises, chiefly in the remedial gymnasium, were stressed for 4 to 6 weeks after the cast was replaced by elastic bandage and a longitudinal arch support; the support was discontinued at once if it did not add to the patient's comfort. Eighty percent of the patients derived more benefit from walking exercises than from physical therapy, which was continued only for testing purposes.

In several of the 82 cases, some drainage and some necrosis of the skin were found at the first, and sometimes at the second, change of plaster, but in all but one instance, healing was complete at the end of 3 months. This was true even when there had been a considerable preoperative breakdown of the scar in compound fractures.

No statistics of any value are available for the results of triple arthrodesis at Fletcher General Hospital because of the limited period of postoperative observation. Roentgenologic examination at the end of 3 months, however, showed bony fusion of the involved joint in all but a few of the cases; and in those in which fusion was not yet complete, the outcome promised to be satisfactory. In every case, the osteoporosis present before operation had disappeared.

Clinically, all of these patients regarded themselves as improved from several standpoints: relief of pain on walking, especially on uneven ground; disappearance of edema; and elimination of limping, or great improvement in the gait. A number of these patients had previously been submitted to arthrodesis of only involved joint without relief. All of them were separated from service, but in many instances the result was so satisfactory that a Certificate of Disability for Discharge scarcely seemed justified.

INJURIES OF THE ASTRAGALUS

Injuries of the astragalus were usually incurred in jumps and falls, though they might occur after dislocations of the ankle. The differential diagnosis included osteochondritis dissecans, os trigonum, and anomalous bone.

Any discussion of these injuries should begin with the statement that, even with the best of treatment, they were likely to be disabling (*8*). Simple fractures responded to management in a walking cast for a few weeks. Fractures of the neck without displacement usually could be reduced successfully, after which a plaster cast, extending above the knee, in slight

flexion, with dorsiflexion of the foot, was used for 8 to 12 weeks before weight-bearing was permitted.

Fractures of the neck with displacement and fractures of the body could present extremely serious problems, chiefly for circulatory reasons (*9*). The circulation to the astragalus comes from the anterior tibial artery. Several small nutrient branches are carried in the dense astragalo-scaphoid talonavicular ligament, which extends as a broad band over the top of the neck of the astragalus. Several small arteries in this ligament perforate the dorsomedial aspect of the neck, which apparently has no other vascular supply. A fracture through the neck of the astragalus, therefore, however minute, can cause loss of the blood supply to the portion of the bone posterior to the injury, with resultant avascular necrosis.

Fractures of the body of the astragalus were usually of the crushing type, with the force transmitted longitudinally, frequently with extreme disruption of the articular surface. If there was no displacement, plaster fixation was employed for about 8 weeks with the foot in dorsiflexion and otherwise neutral, without weight-bearing. If displacement had occurred, reduction was as exact as possible, but it was usually difficult to achieve and was frequently unsuccessful; avascular necrosis was always a possibility in the portion of the body posterior to the fracture line.

If the fracture of the body was comminuted, reduction was even more difficult and the circulatory problem was even graver. Reduction could be obtained by manipulation or by open methods. However, necrosis was frequent, so frequent, in fact, that it was always well to consider, at the primary operation, some such procedure as subastragaloid arthrodesis to bring in circulation in an attempt to avoid bone deformity and traumatic arthritis with resulting disability. In very severe comminutions, astragalectomy might be considered (fig. 176), or fusion of the neck and head of the astragalus to the tibia. Another possibility was the fusion, after partial astragalectomy, of the head and neck of the astragalus to the tibia. Still another possible procedure after astragalectomy, as recommended by Schrock and his associates, was the fusion of the tibia and the os calcis, which would provide a painless weight-bearing foot (*10*). These observers also suggested the use of a portion of the astragalus as a wedge adapter when arthrodesis was done. The Schrock technique was most useful if sclerotic changes had occurred in the fractured body. Immobilization was maintained for a sufficient time for possible revascularization without loss of bone conformity, since the Schrock operation was always followed by limitation of subastragalar motion.

ANOMALIES OF THE ANKLE

In a study of anomalous conditions of the feet at the station hospital at Fort Riley, Kans., Maj. Charles J. Sutro, MC (*11*), found the astragalus involved in a number of cases:

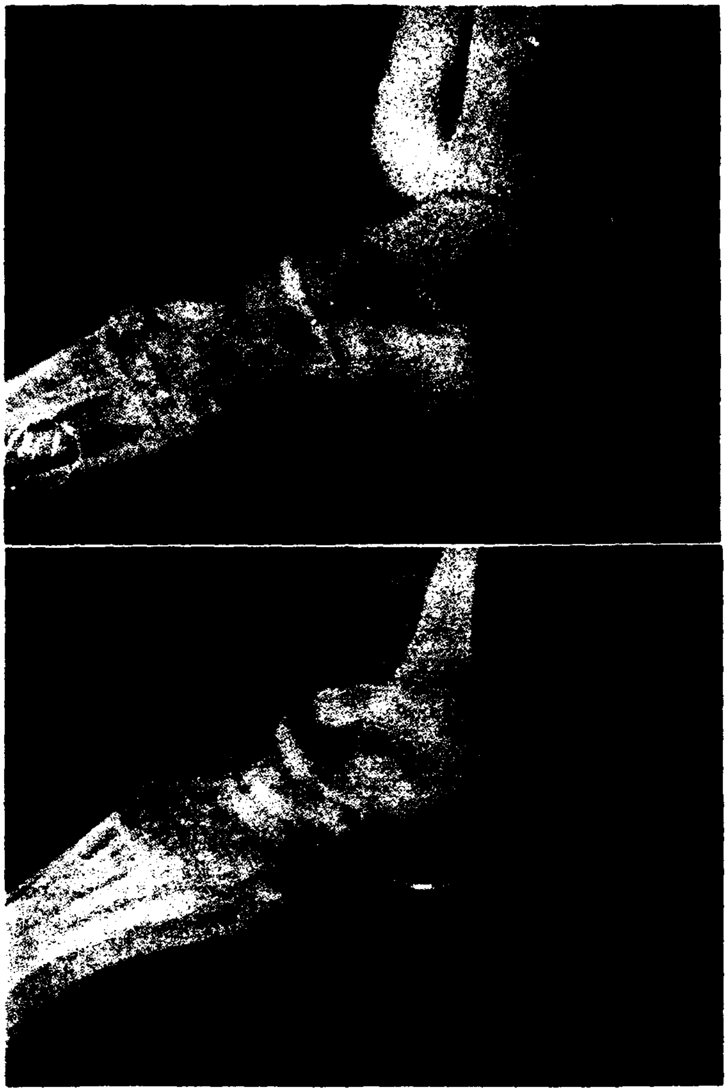

FIGURE 176.—Astragalectomy. A. Lateral roentgenogram of foot showing dislocation between talus and adjoining bones of foot. The injury was sustained in the crash of a C–47 plane in Italy. B. Lateral roentgenogram of same foot following astragalectomy performed overseas. (Snedecor, S. T.: J. Bone & Joint Surg. 28: 332–342, April 1946.)

1. Several instances of recurrent painful and enlarged ankle joints resulted from circumscribed areas of subchondral bone undergoing avascular necrosis on the superior articular surface of the astragalus. Tenderness was present on pressure over the anterior aspect, and roentgenographic examination showed a detached island of subchondral bone in either the lateral or the medial portion of the superior articular surface.

2. In two cases, fragments removed from the body of the astragalus were found to be almost completely detached from it. The pits from which

FIGURE 177.—Osteochondromatosis of ankle joints. Lateral roentgenograms of left and right ankles showing calcified masses in anterior compartment of left ankle joint and in anterior and posterior compartments of right ankle joint. (Sutro, C. J.: Disabilities of the Foot Other Than Those Incurred by Training. [Unpublished data.])

they were removed were covered with firm yellowish tissue that prevented rapid reorganization of the defect. Histologic studies of excised portions of the articular cartilage and attached subchondral bone showed vital cartilage but necrosis of the osseous elements (osteochondritis dissecans).

3. In tw cases of painful feet, the cause was found to be bony masses in the anterior and posterior compartments of the astragalotibial articulation. In both instances, there was considerable limitation in the range of dorsal and plantar flexion, and masses could be palpated on the anterior and posterior surfaces of the involved ankle. Roentgenographic examination revealed several large, circular, bony or calcified cartilaginous bodies within the articular cavity. Both patients had to be separated from service (fig. 177).

4. Another instance of disability of the feet was caused by anomalous ossicles projecting from the medial aspects of the astragalus and the calcaneus. Each beaklike projection of bone formed part of an accessory articulation that was sometimes the seat of a premature traumatic osteoarthritis. These bony masses impeded movement of the calcaneus and the flexor tendons, irritated and thickened the overlying skin, and interfered with wearing of military shoes. Examination revealed an anomalous bony mass on the medial aspect of the astragalocalcaneal articulation. Passive subtalar movements of the os calcis were missing, and the attempted maneuver caused severe pain. Oblique roentgenographic projections showed the bony breaks on the medial surfaces of the astragalus and the calcaneus. The joint space between these two structures was narrow, and

the contour of the subchondral region was definitely irregular. The removal of the beak in one case revealed, on histologic examination, advanced osteoarthritis. The patient was relieved of all symptoms after operation, but had only a minimal increase in the range of movement of the calcaneus.

5. In three cases, recurrent painful ankles followed ankle injuries which were presumed to be severe sprains. Examination showed moderate enlargement of the affected area, with minimal limitation of dorsal and plantar flexions. There was tenderness on pressure over the capsular tissues, especially on the posterior aspect of the articulation. Roentgenologic examination showed an unusual linear ossification at the posterior and distal portions of the tibia, and the condition was thought to be similar to Pelligrini-Stieda disease (p. 223).

6. A considerable number of men were observed in training with histories of previous sprains and with ankle joints that were greatly relaxed because their medial and lateral ligaments were torn or greatly stretched. Only a brief experience was necessary to show that men with such joints could not possibly withstand the rigors of basic training, and it was wisest from every standpoint to separate them from service promptly on Certificate of Disability for Discharge.

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CHAPTER XXVI

Injuries and Other Lesions of the Feet

Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

Section I. Civilian-Type Injuries and Lesions

HISTORICAL NOTE

Evolution of Program of Foot Care in World War I

When the United States entered World War I, the potential efficiency of soldiers' feet became a matter of paramount importance (*1*). Evaluation was difficult for medical members of local draft boards, camp surgeons, and even trained orthopedic surgeons. It required an adequate appreciation of the difference between the structure of feet and their functional performance, a comparative understanding of the demands of civilian occupations and avocations and the demands of military service, and an ability to evaluate the symptoms and signs of foot strain in their incipiency. Evaluation was additionally confused by the attitude of the individual soldier toward military service. The man who desired to minimize or conceal past or present trouble with his feet, so that he would be accepted for service, had to be differentiated from the man who exaggerated symptoms and signs, or simulated them, so that he could avoid the draft. An occasional athlete was rejected because his arches were low, while many men with normally high arches but feet that were potentially weak functionally were accepted, and some men with grossly defective feet were sent overseas.

The situation was clarified when certain policies were put into effect:

1. A routine system of examination of the feet was worked out by which two medical officers and four clerks could make and record a hundred examinations an hour.
2. With prompt recognition of remediable foot defects, men with them were segregated and put into a graduated system of training. At the same time, men with irremediable disabilities who had been inadvertently passed by their draft boards were promptly separated from service. The number of these men was considerable among the early recruits, and when they reached camp, the number of orthopedic surgeons was limited and medical services were not yet properly organized.

3. In the beginning, it was difficult to determine which men were worth rehabilitating in the military sense. It was the custom in several camps to organize enlisted men trained to examine the feet into a special detail. Draftees were examined by them within 24 hours after they reached camp, their shoe measurements were verified, and the necessary alterations were prescribed and made in their shoes. They were then assigned to drill sections suitable to their estimated ability. Foot exercises were introduced at setting-up drill, and those unable to endure heavy marches were required to perform additional exercises.

When objective signs were few, it was naturally difficult to separate the real foot defectives from timid men and actual malingerers. Nevertheless, the system just described worked out reasonably well from the standpoint of immediate results. In one camp, for instance, of 822 men examined over a 4½-month period, 614 were returned to their organizations, 447 of them to full duty. The remaining 167 men were recommended for domestic duty or discharge from service.

Instructions in Foot Problems

It was realized from the beginning that a satisfactory solution of foot problems required the cooperation of the line officer, the medical officer, and the soldier himself. From the beginning, therefore, systematic instruction in foot problems was given to all three groups.

A concise set of instructions for the care of the feet was prepared for The Surgeon General, for distribution to camp surgeons, by members of the American Orthopaedic Association. This material, which was first distributed in mimeographed form, later served as the foundation of the first chapters of the manual entitled "Military Orthopaedic Surgery" (*2*). Still later, circulars were prepared with special instructions for examination of the feet and salvage of men with defective feet. These circulars formed part of the clinical courses in general orthopedic surgery given at Camp Greenleaf, Ga., other camps, and special schools. At Camp Greenleaf, the course lasted 4 weeks, there were 25 medical officers in each class, and a new class entered each month. Courses at universities lasted 6 weeks. Later in the war, a more intensive course in foot prophylaxis and treatment was given at Camp Greenleaf with other orthopedic instruction.

Line officers and candidates for commissions received at least 3 hours of instruction in the care of the feet and simple orthopedic conditions affecting the feet.

Enlisted men received at least an hour of practical demonstrations in the care of their feet. The instructions were given by the organizational surgeons under orthopedic supervision.

In the beginning, an effort was made to assign to training camp duty only medical officers with orthopedic experience. The number of trained officers soon proved entirely inadequate, and assignments had to be made

from officers trained only in the courses just described. The plan was then devised of dividing the country into zones, each of which was visited by a consulting orthopedic surgeon who spent 7 to 10 days in each camp, fulfilling the triple functions of consultation, instruction, and inspection.

Correction of Defects

Instructions for the care of the feet emphasized the importance of recognizing slight deviations from normal as potential sources of disability. These deviations included pronation, flattening of the longitudinal and transverse arches, limitation of dorsal flexion, cavus of a degree sufficient to produce disability in civilian life, and similar conditions likely to be aggravated by the demands of training.

Of all the orthopedic work done on the feet, the prophylaxis and correction of the following defects were regarded as producing the best results:

1. The defects just listed and correctable by simple alterations in the shoes. Men with these defects were assigned to special squads for graduated training, corrective exercises, simple wedging of the heel and sole of the shoe, and provision of slightly higher heels for men with short heel cords. Of this group of defects, cavus was the most difficult to remedy.
2. Defects usually producing disability incompatible with full military duty. It was frequently possible to salvage men with these defects for service by assigning them to noncombat duties.
3. Hallux valgus, contracted foot, hammer toe, and other conditions benefited by surgery in civilian practice. It was hoped that similar results could be accomplished in the Army, but they were not. Instead, the results were failures in every respect, including the economic, and surgery for these conditions was eventually forbidden by The Surgeon General, ironically on 12 November 1918, the day after the Armistice (*3*).
4. Defective development and muscular strength. These deficiencies were perhaps the most trying of all to evaluate and correct. Estimates were based on both form and function, though these factors were not necessarily correlated. The requirements of good foot function are normal flexibility and good muscular development, and when only poor muscular development was evident, the decision as to the soldier's functional ability was not easy. The height of the arch was found to be of little significance. Similarly, pronation was often a purely postural defect; only when it was complicated by poor muscular development of more than moderate degree or by impairment of flexibility was it a serious problem. In doubtful cases, evaluation of functional ability settled the matter.

INDUCTION STANDARDS IN WORLD WAR II

The following standards of acceptability for service with specific reference to defects of the feet (cited in substance) were in effect from October 1940 through 19 April 1944 (*4*):

Criteria for General Service

Men were acceptable for general service with:

1. Pes planus, unless accompanied by marked deformity, rigidity, or weakness, or of such a degree as to have interfered with a useful vocation in civil life. On 1 February 1943, this specification was changed to read as follows: "Flat foot unless accompanied with symptoms of weak foot or when the foot is weak on test. Pronounced cases of flat foot attended with decided eversion of the foot and marked bulging of the inner border, due to inward rotation of the astragalus, are disqualifying regardless of the presence or absence of subjective symptoms."
2. Hallux valgus, unless severe.
3. Clubfoot of slight degree if tarsal, metatarsal, and phalangeal joints are flexible and the condition permits the wearing of a military shoe and, in the opinion of the examiner, will not interfere with the performance of military duty. This category was dropped in the 19 April 1944 regulations.
4. Slight claw toes not involving obliteration of the transverse arch and not interfering with the wearing of a military shoe. This category was dropped after 19 April 1944.
5. Hammer toe if it is flexible and does not interfere with the wearing of a military shoe. This anomaly usually involves the second digit and, unless it is rigid, it is not a disqualifying defect. The last sentence was dropped after 15 March 1942.
6. Ingrowing toenails. After 15 March 1942, the specification was added that they should not be severe.

Criteria for Limited Service

Men were accepted for limited service with:

1. Abduction and pronation (knock-ankle) not associated with rigidity of the tarsal joint or deformity of the foot. The statement that this defect is remediable with proper foot exercises and correct shoes was dropped after 15 March 1942.
2. Loss of great toe.
3. Loss of dorsal flexion of great toe.
4. Hammer toe with rigidity. This specification was dropped after 19 April 1944.
5. Other defects of the feet which disqualify for general military service but do not prevent the registrant from wearing a military shoe and which have not prevented his following a useful vocation in civilian life.
6. Clubfoot of slight degree if tarsal, metatarsal, and phalangeal joints are flexible, permit wearing of the military shoe, and, in the opinion of the examiner, will not interfere with the performance of military duty. This category was added on 19 April 1944.
7. Slight claw toes not involving obliteration of the transverse arch and not interfering with the wearing of a military shoe. This category was also added on 19 April 1944.
8. Other defects (abnormalities) which, in the opinion of the examining physician are disqualifying but which are remediable and which have not prevented the registrant from following a useful vocation in civil life. This category was dropped after 15 October 1942.

Criteria for Rejection

Men were not acceptable for service with:

1. Pes planus, if accompanied by marked deformity or weakness, or of such degree as to have interfered with following a useful vocation in civil life.
2. Obliteration of the transverse arch associated with permanent flexion of the small toes (claw toes).
3. Hallux valgus if severe and associated with marked exostosis or bunion, especially when there are signs of irritation above the joint.
4. Clubfoot if marked in degree or if it interferes with the wearing of a military shoe.
5. Osteoarthritis or rheumatoid arthritis or chronic arthritis from any cause. This specification was added on 19 April 1944.
6. Plantar warts on weight-bearing areas. This specification was also added on 19 April 1944.[1]

GENERAL CONSIDERATIONS

Classifications of Disabilities

Disabilities of the feet were classified in several ways. At one training camp, feet were classified as follows (*5*):

1. Feet with good architecture that showed evidence of acute strain or of spasm of either the calf or the peroneal muscles.
2. Feet that showed various degrees of pronation.
3. Feet that showed bunions, cavus formation, and mild congenital deformities, especially of the forefoot and of the varus type.

At another hospital, the classification was based upon the potentialities of treatment (*6*):

1. Feet for which treatment was not essential, but in which it might be beneficial in relieving mild symptoms.
2. Feet which needed treatment and for which treatment was likely to be successful. This group was the largest and most important group of foot disorders encountered. It included the lesions which would result in disability without proper treatment, but for which treatment could usually be expected to result in complete recovery. In this connection, the difference between civilian and military criteria of results must be pointed out again. In civilian life, the orthopedic surgeon accomplishes the best results to be expected under special circumstances. This criterion will not do for the Army, in which any result short of perfection—that is, full return to military duty—must be classified as unsatisfactory, since in all military surgery, the primary objective is to keep on duty the largest possible number of soldiers.
3. Feet for which treatment could not be expected to be satisfactory.

[1] It seems a specification wasteful of manpower in view of the many permanent cures of these warts which can be accomplished by simple methods.—M. C.

Still another category, probably the most practical of all, classified feet as (1) asymptomatic, regardless of the anatomic and clinical findings, and (2) symptomatic.

Unsatisfactory Results of Therapy

The foot problem was a general one, of as much importance in the AAF (Army Air Forces) as in the Infantry because all AAF personnel had to undergo the same rigid basic training as other soldiers. Foot conditions were the subject of discussion at practically every one of the AAF conferences in 1943 (*5*). Statistics reported from one large camp in the South showed that from 0.3 to 1.0 percent of the troop strength had foot complaints. The proportion sounds small and is small, but numerically the numbers were very large and these men occupied a great deal of time and attention in dispensaries and clinics. Many station hospitals reported that from 40 to 50 percent of their orthopedic admissions concerned the feet. At the AAF conferences, it was agreed that about 25 percent of all orthopedic problems had to do with the feet, with conditions existent before induction forming 70 percent of all foot problems and 90 percent of all problems related to the arches.

None of the methods employed to solve foot problems were really satisfactory. Alteration of shoes and provision of arch supports were seldom satisfactory. Whirlpool baths, massage, stretching, and other foot exercises were equally unsatisfactory. The best results were obtained with special training programs, such as that developed by Capt. Ashley Pond, MC (*6*), at the 1st Convalescent Camp in India, in which the capacity of the feet was evaluated from the standpoint of tolerance and the men were actually taught how to walk. The difficulty in all such programs was that they were adapted only to special situations; time could not be taken for them in training camps or in combat situations overseas.

Elective surgery for most of the more or less static foot conditions encountered, such as pes cavus, hallux valgus, spastic flat foot, hammer toes, and arthritis of various origins, simply did not pay off in terms of salvage of combat soldiers. Indeed, it often made their condition worse. By the end of the war, it was almost universally agreed that only very occasionally was elective surgery on the feet indicated in military practice.

The story in most of these cases was the same. As a rule, the man did not report to the orthopedic clinic until he was suffering considerable pain and discomfort, the same symptoms he had suffered from in civilian life. In those circumstances, they had been endurable because he could select the shoes he found most comfortable, and he could adjust walking and standing to what could be tolerated. On induction into the Army, everything changed. He had to wear high-top GI shoes, undoubtedly the best shoes for the greatest number of soldiers, but not for a man with abnormal feet. He had to begin at once standing, drilling, marching, and

other activities without regard to his tolerance. Change to better fitting shoes sometimes alleviated the symptoms. Sometimes relief was obtained by wearing low-quarter shoes, which could be prescribed by the medical officer with the concurrence of the company commander (p. 789). Relief from strenuous activities for a few weeks, particularly walking and standing, might prevent the development of calluses and corns and save the soldier from later loss of time. If these measures were not effective, orthopedic alterations of the shoes came next, followed by a trial of arch supports if this seemed indicated. In many such cases, however, experience, particularly in training areas, repeatedly made it clear that time was saved if real foot disabilities were recognized promptly and the men were reclassified for limited service or separated on a CDD (Certificate of Disability for Discharge). As the Consultant in Orthopedic Surgery, Fourth Service Command, bluntly put it, "You will never make a combat soldier out of a foot complainer," and a great deal of time and effort was expended in World War II trying to do just that.

Many men with bad feet probably never should have been inducted, but many had learned to get along with their difficulties in civilian life and might have become useful soldiers if more attention had been paid to graduating the strain on their feet during the early days of training. If orthopedic surgeons had been permitted to advise commanding officers about foot problems before basic training of new inductees, classifying them according to the amount of exercise they could tolerate immediately and later, there would undoubtedly have been less foot disability in World War II than there was. Similarly, regular inspection of the feet after long marches would have decreased the number of days lost from duty. Whether, as already mentioned, time can be taken during wartime for such policies is another matter.

A few other general statements might be made about foot disabilities at this point:

Best results were obtained in their management when treatment was conducted in orthopedic clinics and was preventive as well as therapeutic.

There was no doubt that modern footgear was of prime importance in producing many of the static foot disorders, with associated muscular weakness and anatomic changes, encountered in World War II soldiers. There was also no doubt that the GI shoe had a number of undesirable features and was frequently very poorly fitted (p. 784).

Examination included both feet. It was conducted with the shoes and socks removed, the pants rolled to the knee, and in both the sitting and the standing position. Roentgenologic examination was always part of the routine.

Some orthopedic surgeons did not consider special exercises advisable during basic training, on the ground that the muscles were already being developed as rapidly as possible. Results were better if the man worked all day in a mechanically advantageous position in the training routine

rather than if he performed 15 minutes daily of specialized, isolated muscle exercises.

Malingering

Finally, the question of malingering always had to be taken into account in dealing with foot complaints. The suspicion was frequently justified in men who objected to KP or guard duty. At one airfield, a "forced exercise" battalion was maintained under strict medical supervision for all types of actual and suspected malingerers, many of them men with flat feet. A surprising number were thus rehabilitated, though how permanently is not known. The question comes up again, that in wartime, there is simply not the time or the personnel for this kind of special effort, particularly when the permanent duration of satisfactory results has not been established.

FOOT STRAIN

So-called foot strain occurred in many grossly normal feet when they were subjected to the unaccustomed and excessive stress of walking, marching, and working all day on the feet. The only symptom was pain or discomfort in the feet and legs on walking and marching, which was annoying and inconvenient but seldom disabling enough to keep a man from full duty. Neither cramping nor swelling of the feet was complained of. The pain usually appeared in the first few days of training and was earlier and more severe in obese, short-legged soldiers, who had to take the same stride as longer-legged men in the ranks.

When the condition was simple foot strain, examination showed grossly normal feet structurally, with a full range of motion in all joints, including the joints of the ankle. There was no pain at the extremes of motion, which was an important consideration in differentiating simple strain from more serious conditions. There was moderate tenderness over the muscles of the calf, the fascia and ligaments of the sole of the foot, and the capsules of the midtarsal joints, but it was never extreme nor was it well localized. It was most conspicuous in the leg, along the medial border of the upper tibia, apparently as the result of strain at the origin of the tibialis posterior. In the foot, tenderness was most marked at the posterior attachment of the plantar fascia and beneath the talonavicular joint.

Treatment was seldom required in simple foot strain. Many patients, perhaps the majority, in fact, never reported on sick call, assuming that the discomfort they were experiencing was part of the normal conditioning process. If they did report, it was important that the dispensary surgeon should recognize the strain syndrome for what it was. Correct management was to explain the situation to the patient; instruct him in correct foot hygiene, including a nightly hot bath; check the fit and con-

dition of his shoes; and avoid any form of treatment that would keep his attention centered on his feet. Taping was particularly undesirable. It relieved pain because it supported the feet and limited joint motion, but it also permitted the muscles to rest when they should have been forced to work until they became strong enough to do so without pain. For the same reason, patients with simple foot strain were not put on light duty or kept in quarters. Such practices only postponed the time of complete recovery and made it necessary, when the man returned to duty, to start the hardening process all over again.

A special type of chronic foot strain was observed in hospital patients as the result of the original illness or injury combined with prolonged bed rest and the use of loose-fitting canvas slippers about the ward. A certain amount of this kind of foot strain would have been avoided if all patients had been required to wear shoes as soon as they became ambulatory. If weakness was extreme, arch supports were used temporarily.

FOOT STRAIN OF POSTURAL ORIGIN

Pain in the foot was not always the first symptom of foot problems. The presenting symptom might be a sense of fatigue in the lower back, the hips, the legs, and the ankles long before any localization in the feet occurred. Aching pains and cramps in the legs at night were also common symptoms, which for some reason patients were not inclined to mention until they were specifically questioned about them. All of these manifestations pointed to possible foot disorders and indicated the need for a careful investigation of the feet.

Faulty body posture was a common cause of foot disability. It was usually manifested by pronation and could be recognized by the outward rotation of the calcaneus, with dropping of the inner border of the foot. As a result, the body weight was thrown on the medial aspect of the foot and symptoms of strain of the longitudinal arch followed. The etiologic factor was the relative weakness of the posterior tibialis muscle. This type of foot disability was often associated with an abnormal prominence of the medial border of the navicular bone, with resulting poor attachment of the posterior tibialis. It was sometimes associated also with an accessory navicular bone.[2] According to Lt. Col. Albert L. Bershon, MC (*7*),

[2] Eight cases of tarsonavicular anomalies were reported from the regional hospital at Fort Riley, Kans., by Maj. Charles J. Sutro, MC (*8*), including both accessory navicular bones and enlarged navicular tubercles. The bony prominence was caused by an accessory center of ossification, which might or might not fuse with the tarsonavicular. When the anomalous ossicle was irritated by the pressure of the GI shoes, an overlying bursa frequently developed, which was highly sensitive to palpation and pressure. Because of the enlargement of the navicular area, the appearance of the involved foot suggested true flat foot, for which the anomaly was sometimes mistaken.

Roentgenographic examination showed an ossicle on the medial aspect of the navicular bone.

The aberrant bone interfered with the normal attachment of the posterior tibial tendon, and therapy was, therefore, directed toward measures to prevent weight-bearing in the navicular region. Permanent cure sometimes required resection of the prominent navicular tubercle and transplantation of the insertion of the posterior tibial tendon.

20 to 25 percent of all feet studied roentgenographically, showed accessory bones in one location or another.

Examination usually showed, in addition to pronation of the heel, tenderness over the astragalonavicular joint, where pain was likely to be localized. Pain might be caused by forcing pronation of the forefoot. There was no swelling or limitation of motion.

Treatment was directed toward correction of pronation and of the excessive lengthening and weakness of the posterior tibialis. Mild cases were treated with a medial wedge under the heel of the shoe, three-sixteenths of an inch thick along the inner border and tapering off halfway across the heel. More serious disabilities were managed by arch supports.

It was not at all unusual for a trainee who suffered from chronic foot strain originating in poor posture to present himself with an acute sprain, usually within the first 2 weeks of basic training and usually after a long march. In addition to the signs characteristic of chronic strain, swelling through the midtarsal region was conspicuous.

If the sprain was severe, rest from weight-bearing was necessary. Taping the foot in slight inversion was useful, as was the application of a firm piece of felt, about one-half of an inch thick, under the longitudinal arch. After the acute symptoms had been relieved, pronation was corrected, to prevent recurrence.

SPRAINS

Minor sprains of the feet occurred chiefly on obstacle courses, during jumping, and were not difficult to recognize. The injury might involve the plantar fascia as well as the joints. Taping was used to support the injured part. If there was any swelling, relief from weight-bearing in quarters was necessary for a few days.

PAINFUL HEELS

Painful heels were frequent in trainees, but usually responded to the use of a heel pad with a hole in it and a high longitudinal arch support. If these measures were not effective, a change in assignment was necessary.

FRACTURES

Fractures of the Toes

Fractures of phalanges of the toes resulted from striking the toe against a solid object, falls from heights, athletic activities, and routine training activities. Medical officers were sometimes inclined to minimize

fractures of these and other small bones of the foot because they did not usually cause great disability. This was an error. If standard principles of fracture management were ignored, the toe could assume the hammer position or some other malposition, with resulting malfunction of nerves, blood vessels, and tendons. Later, traumatic arthritis was also always a possibility in these injuries of small bones.

If the fractures were not compound, they usually caused little more than temporary disability. Since they were seldom displaced, they seldom needed reduction. The best plan was to splint them by adhesive to the adjacent toe (toes), which served as a splint, or on a plantar hairpin tongue blade, for 2 or 3 weeks. If there was displacement or overriding, reduction was necessary, with immobilization in plaster, preferably a boot with a wire loop incorporated in it and extending out beyond the toes.

Compound fractures of the big toe were always potentially serious. They were associated with considerable immediate disability, and alterations in weight-bearing and ambulation often made it impossible for the patient to return to full field duty. Reduction of the fracture and application of a banjo splint were the standard treatment.

Fractures of the sesamoid bone under the great toe could be both painful and troublesome. They could be caused by forcible hyperextension of the great toe or by falls with the weight on the ball of the foot, in which case they were often crushing. They were easily overlooked without particularly careful roentgenographic examination; they had to be distinguished from normal sesamoid bones, which have a more smoothly rounded appearance than the sharp, irregular appearance of the edges of a fractured bone.

In fresh sesamoid fractures, immobilization in a cast with the great toe slightly flexed, was maintained for about 3 weeks, after which an anterior metatarsal support was used in the shoe for a few days. In older fractures, with nonunion and pain, felt pads were used. If they were not successful, excision of the damaged bone was indicated.

Fractures of the proximal end of the fifth metatarsal bone were usually caused by an inversion injury, which might take several forms: a fracture through the tuberosity, a fracture of the area just distal to the tuberosity, or merely pulling off of the tip of the tuberosity. Symptoms were pain on walking or standing, localized tenderness, and swelling. Separation was seldom marked, and careful roentgenographic examination was often necessary to demonstrate the fracture.

If the fracture was undisplaced, a plaster boot was worn for 4 or 5 weeks, after which the position was checked by roentgenograms. If healing was slow, immobilization was maintained for another 3 or 4 weeks. If the fracture was displaced, reduction was carried out as accurately as possible—which was not always a simple procedure—and immobilization was maintained as long as necessary. Reduction sometimes had to be post-

poned for several days until swelling had disappeared. Traction through the soft tissue pulp of the toe, which was used in some hospitals, was an undesirable method.[3]

Fractures of the Tarsonavicular Bone

Fractures of the tarsonavicular bone seldom occurred alone. They were frequently associated with dislocations. The usual mechanism of injury was catching the heel on a step and falling forward and downward so forcibly that the dorsal ligament pulled off a fragment of bone. There was usually little displacement. The standard treatment was immobilization in plaster up to the knee for 4 weeks.

Fractures through the middle portion of the navicular involved two joint surfaces, and accurate reduction, which was extremely important, was often extremely difficult. The Lewin technique was generally used (*10*): Manual traction was applied through the long axis of the foot, with the heel fixed, by inversion, eversion, plantar flexion, and finger-molding. Plaster was applied for 3 weeks with the forefoot everted and plantar-flexed, after which immobilization was maintained in the normal position for another 2 or 3 weeks.

Fractures of the medial tubercle of the navicular bone had to be distinguished from os tibiae and accessory navicular bones (p. 743n). They often resulted in nonunion.

Results of treatment in fractures of the tarsonavicular were not very good. Callus often piled up to such a degree that its surgical removal was necessary because the pressure of the shoe on it could not be tolerated. If the joint surface was involved, traumatic arthritis might result, with hypertrophy of the dorsal portion of the talonavicular joint. Arthrodesis was often necessary to relieve pain. The principal cause of poor results in these fractures was circulatory disturbances. Even after accurate reduction, avascular necrosis could occur and make arthrodesis necessary. Results were often poor.

Fractures of the Os Calcis

Fractures of the os calcis were frequent in trainees, particularly those in the AAF training program. Even simple fractures could be disabling.

[3] At the 20th Station Hospital in Guadalcanal, standard methods of treatment of fractures of the base of the fifth metatarsal were regarded as inefficient and the following method was devised (*9*):

The injured foot was painted with liquid adherent, and as it dried, snug-fitting stockinet was rolled over the painted area from toes to ankle. A well-fitted arch support was then applied to the plantar surface of the foot, over the stockinet, and fastened securely in place with adhesive plaster. The dressing was completed by folding back the redundant edges of the stockinet. The patient wore a high shoe and was permitted as much activity as he could tolerate without using a cane or a crutch. His condition was checked every 4 to 5 days, to be sure the support was adequate and the skin was in good condition. After the dressing had been worn for about 3 weeks in all, with changes as necessary in the interim, the arch support was transferred to the shoe and worn for another 3 weeks.

The average loss of duty time with this method was 2½ days.

Os calcis fractures were usually treated in balanced suspension skeletal traction in a Thomas splint, with a Kirschner wire through the posterior fragment. The anatomic results were usually satisfactory. The functional results frequently were not, because of the structural changes that had occurred; when the fractures involved the articular surfaces of the os calcis, these changes included loss of angle, widening of the bone, dropping of the arch, and flat foot, often with bony exostoses underneath the fibular external lateral malleolus. These changes limited inversion and eversion, and produced pain and disability on walking, particularly over uneven ground. Plantar spurs sometimes appeared after the injury. Even when the changes were correctible, various residua were likely to render the patients unfit for active duty, and many of them had to be separated from service on a CDD.

Official policies of management.—Official Medical Department policy in injuries of the os calcis was set forth in May 1946 as follows (*7*):

1. When a fracture or avulsion of the posterior portion of the os calcis occurred at the tubercle, a portion (portions) was displaced upward and backward, partly by the pull of the Achilles tendon and partly by the causative force. A duckbill type of fracture resulted. If there was little or no displacement, immobilization with the knee flexed and the foot plantar-flexed was usually all the treatment needed. The original cast was left undisturbed for 5 or 6 weeks, then was replaced with a short cast, with the foot in neutral position, for 2 weeks. If displacement was considerable, open reduction, with fixation with a screw or nail, had to be used.

2. Fissure fractures occurred vertically through the posterior portion of the body or the tubercle. Displacement was infrequent, but if it occurred, lateral compression was necessary before immobilization. Otherwise, simple plaster fixation was instituted for about 6 weeks.

3. A fracture of the sustentaculum tali might occur alone, with this portion of the bone broken off or crushed into the body of the os calcis. Fractures of this type caused flattening of the longitudinal arch, which, if it was not corrected, left a painful heel. Special positioning might be necessary to demonstrate the deformity roentgenologically.

If displacement was present, reduction was attempted under anesthesia, with the foot inverted and plantar-flexed. Pressure was then applied upward against the fracture on the inner side of the foot, with the forefoot pronated and the heel inverted. After reduction and reformation of the arch, plaster fixation was maintained in this position for 6 to 8 weeks. The cast was replaced by a wedge on the inner border of the heel of the shoe and an arch support, preferably of firm felt.

4. Fractures of the body of the os calcis, of the crush (squash) type, which were the most severe encountered, were frequent. The mechanism of the injury explained the damage: It usually resulted from a fall from a height, with the weight taken on the foot. The subastragaloid joint was invariably disrupted, with shortening and broadening of the body of the os calcis, eversion of the heel, upward displacement of the posterior portion, and loss of the tuber angle. Associated jack-knifing of the spine was usual; in every such injury, a study of the dorsolumbar spine was necessary, to rule out compression fractures of the vertebral body.

Therapy.—Bankart (*11*), who bluntly described the results of treatment of crush fracture of the os calcis as "rotten," thought that they bore no relation to the accuracy of reduction. In his opinion, the best results were achieved when complete triple arthrodesis was performed as a pri-

mary measure. The problem was a serious one, for pain often persisted in spite of good surgery, though the reverse might occasionally be true and patients who would be expected to have pain would get along remarkably well.

Severe swelling followed many crush fractures, and reduction had to be delayed until it had subsided, even if this took 10 to 12 days. Elevation of the extremity, heat therapy, and light massage were sometimes used in an attempt to shorten the interval. A small residual amount of swelling could occasionally be massaged out under general or spinal anesthesia.

Reduction and fixation were done with great care. Impaction was broken up with the palms of the surgeon's hands clasping the heel and the fingers interlocked behind it. The tissues under the skin gave the feeling of a bag of gravel. A wedge, or the edge of a table, could also be used to break up the impaction.

With the knee flexed to about 90 degrees and the foot plantar-flexed, a Böhler clamp was applied under the malleoli, and the pathologic widening of the bone, especially under the external lateral malleolus, was reduced until it approached the width of the opposite intact foot. With the clamp in place and the ankle plantar-flexed, downward traction was exerted with the hand on the back of the heel while counterforce was exerted upward on the arch under the sustentaculum tali. Upward pressure could also be exerted over a wedge or the padded edge of a board, with the opposite edge at the operator's abdomen. The cutoff upper end of a crutch was also useful for this purpose, as was a metal bar. The downward pull, the upward thrust, and the inversion of the heel combined to mold the arch into position and to reestablish the tuber angle. A lateral roentgenogram was taken after the clamp was removed, to check the accuracy of the reduction.

The cast was applied by an assistant. It was well molded under the malleoli, and the back of the heel, as well as into the arch, while constant downward traction was exerted by the surgeon on the back of the heel, with the foot plantar-flexed, the heel inverted, and the knee flexed to about 90 degrees.

The cast, which was applied with a minimum of cotton sheet wadding, extended from the toes to the mid thigh. After 4 to 6 weeks, it was replaced by a walking cast, extending to the knee, which was worn for another 3 to 4 weeks. Physical therapy was used to improve the circulation and loosen the ankle and the subastragaloid joints. A Thomas heel, with or without a felt arch support, was often applied to the shoe when the patient became ambulatory.

STATIC CONDITIONS OF THE FEET

Hallux Varus-Valgus

Hallux varus was observed in its usual manifestations in Zone of Interior hospitals; that is, tibial deviation of one or both of the big toes. An abnormal increase in the web space between the first and second toes resulted in an unusually wide foot, which interfered with the wearing of the ordinary military shoe. Roentgenograms showed the first phalanx of

the big toe articulating with the tibial half of the metatarsal head. Other anomalies, such as long or short phalanges, were sometimes present also. Military management followed the civilian practice of treating this condition by surgery.

Hallux valgus was also observed in its usual manifestations; that is, a displacement of the great toe toward the other toes, as the result of an abnormal varus attitude of the first metatarsal bone. Only occasionally was the head of this bone intrinsically enlarged; the prominence observed on the medial aspect of the metatarsophalangeal articulation of the great toe was apparent in part because of the fibular deviation of the proximal phalanx. Since, in this condition, the medial portion of the articular head of the first metatarsal bone does not articulate with the proximal phalanx, it was prone to irritation by the overlying shoe, and the resulting bursa was a frequent cause of pain and discomfort. Callosities also were frequent over the plantar aspect of the second, third, and fourth toes. Roentgenograms showed a relative lengthening and thickening of the second metatarsal bone as compared to the bone of the first toe, and also showed an abnormal varus position of the first metatarsal.

Sometimes hallux valgus was so slight as to require no special treatment, which was fortunate, for therapy was not satisfactory. Associated mechanical defects which remained after successful surgical correction of the valgus deformity often converted the surgical success to a practical failure. If treatment of the associated foot strain and the wearing of properly fitted shoes did not give relief, it was unlikely that correction of the condition by surgery would result in a foot that could stand the stress of full military duty. The followup study of 25 such operations at Fort Jackson, S.C., by Lt. Col. (later Col.) Mather Cleveland, MC, and his associates (*12*) proved this point conclusively (p. 110).

Claw Toes

Because of regulations covering induction of men with this condition (p. 94), claw toes serious enough to require treatment were encountered only occasionally. If the men had been inducted in error, they either were put on duty that did not require prolonged marching or standing, or were separated from service on a CDD.

Persistently painful, rigid clawing of the toes sometimes occurred after bony union in fractures of the foot. The clawing was associated with edema and with a rigid deformity of the transverse arch; the metatarsal heads were directed convexly toward the sole of the foot. The rigidity of the toes and the hyperextension of the metatarsophalangeal joints were explained by adhesions, contractures of the tendons and ligaments, and muscle imbalance, with neglect of active toe exercises playing a large part. The question often arose as to why clawing of the toes in normal extremities was so frequently present without pain or disability, in con-

trast to the clinical manifestations of clawing in damaged feet. The explanation was that the parts are mobile when the foot is normal whereas, in the injured foot, clawing of the toes and flattening of the transverse arch are rigid.

Claw toes was a complication preventable in two ways:

1. By frequent, active exercises for all joints of the toes during any immobilization of the foot.
2. By correct fixation, with the plaster never extending beyond the ends of the toes except on special indications. If, for any reason, the toes required protection, a wire bow could be incorporated in the cast, to prevent pressure and permit free motion.

Hammer Toes

Hammer toe is a condition characterized by a flexion deformity at the proximal interphalangeal joint, with partial or complete secondary subluxation of the middle phalanx. When the deformity was localized to one toe, usually the second, dorsal angulation was fixed and could not be corrected by manipulation. The result was inability to wear the military shoe because of the constant irritation of the affected toe by it. Hammer toe was frequently associated with an equinus deformity of the metatarsal bone.

Roentgenograms showed a cone-shaped deformity at the proximal interphalangeal articulation, with subluxation of the middle phalanx.

Men with serious degrees of hammer toe should not have been inducted (p. 94). Conservative therapy was at best only palliative, and the question arose whether, in military practice, elective surgery for this condition was justified, even though in civilian practice, arthrodesis at the involved joint or some tenoplastic procedure usually produced a permanent cure. In June 1942, the Chief Medical Consultant to the Canadian Armed Forces, Col. J. A. MacFarlane, RCAMC, advised against it (and against surgery for hallux valgus) (*13*). Many U.S. Army orthopedic surgeons shared his opinion that a change of assignment was a better solution. Surgeons willing to operate for hammer toes confined their efforts to the second, third, and fourth toes. If the fifth toe was affected, they recommended amputation.

Splay Feet

Splay or hypermobile feet were seen only occasionally. In this disorder, all the joints were involved, particularly the metatarsal joints. The entire foot was greatly relaxed. In the standing position, there was unusual spreading of the toes and a mild depression of the astragaloscaphoid talonavicular area. The range of passive inversion of the foot was extreme. The patient, while keeping his knees together, could approximate the tufts of the right foot to those of the left, which indicated unusual

laxity in the midtarsal articulations, probably as the result of overlengthening of the ligaments and capsules about the articulations. The hypermobility of the feet was often part of a generalized condition evident in other joints of the skeleton.

Complaints were chiefly weakness and pain in the legs and feet. No treatment was of any value. If a man was kept in service, he had to be assigned to light or sedentary work.

Pes Cavus

Pes cavus was not listed as a cause for either rejection or limited acceptability for service, and it was, therefore, encountered fairly frequently in trainees. It was characterized by an increase in the dorsal tilt of the calcaneus or an abnormal equinal attitude of the metatarsal bones. No matter which of these abnormalities was the basis of the condition, foreshortening of the plantar fascia and equinus of the first metatarsal bone were frequently the causes of the symptoms. Relative shortening of the common extensor tendon was an additional reason in some cases for the fixed dorsiflexion of the toes. In others, the fifth metatarsal bone was in the valgus position because of the so-called tailor's bunion. Thickening of the skin or true callosities were often observed over the prominent metatarsal heads. There was frequently an associated varus deformity of all the metatarsal bones. Hammer toes, which were frequently associated, often presented corns on their dorsal aspects.

Pes cavus was readily recognized by the unusual height of the arch and the droop of the metatarsal heads. There was tenderness on pressure over the plantar fascia and the midtarsal articulations. The navicular bone was so prominent on the dorsum of the foot that it often suggested a true exostosis. Roentgenograms confirmed the abnormal dorsal tilt of the calcaneus or the increased equinal attitude of the metatarsal bones observed clinically.

Treatment was generally unsatisfactory. It was based on an attempt to redistribute the body weight over as much of the surface of the foot as possible, by means of a firm, high arch, with the highest point of the longitudinal pad under the navicular bone. A high, wide metatarsal pad was used to elevate the heads of all the metatarsals. The use of a metatarsal bar under the sole of the GI shoe was of little value. Whirlpool baths, used in some hospitals to improve the circulation, gave only indifferent results.

Pes Planus

General considerations.—Army specifications for acceptance or rejection of men with flat feet have been described elsewhere (p. 738). The Army experience indicated that feet presenting pes planus were no more likely to give trouble than feet with demonstrable longitudinal arches.

Flat feet could become subject to strain or other injuries, just as other feet, and could then become painful and otherwise symptomatic, but pes planus was not in itself a condition that would necessarily unfit a man for duty or that would require treatment. It was an interesting observation to civilian orthopedic surgeons in the Army that very few soldiers with normal feet came to the clinics complaining of arch strains in spite of the large numbers seen with pes planus. The situation was the reverse of that in civilian life, in which orthopedic surgeons were seldom consulted for severe flat feet while many patients with feet that were relatively normal structurally came for treatment for chronic severe foot strain. The age group of Army troops during the war was probably the chief explanation for the discrepancy: Younger individuals in service would not ordinarily complain of foot strain, whereas a large percentage of those with flat foot would ultimately come to the attention of the orthopedic surgeon for one reason or another.

Classification.—The Army provided no anatomic or pathologic classification of pes planus, but in practice, the following gradations were recognized:

1. Pronation of the foot associated with faulty posture. This type of foot was usually considered flat by the patient and was often thus diagnosed by the medical officer. As a matter of fact, if the pronation was corrected, a normal longitudinal arch was usually found to be present.
2. A low arch in an otherwise normal foot. A normal longitudinal arch varies from high, approaching the configuration of a mild pes cavus, to complete absence of the arch in congenital pes planus, which was seen chiefly in the Negro. A relatively low arch was not symptomatic because it was low but because of the same disorders that afflicted a structurally normal foot. If a patient had complaints, he should be treated for whatever was causing them, which was not his low arch.
3. A congenitally weak foot. In this type of foot, the arch is not always conspicuously flattened, and there was usually no parallel between the degree of flattening and the severity of the symptoms complained of. The muscles did not hold the arch up on weight-bearing because of their congenital weakness and because, in addition, the joints were flexible and the ligaments loose. Support was necessary to prevent strain on weight-bearing.
4. A congenital flat foot with a completely flat (absent) longitudinal arch. An attempt to create an arch simply created further disability.
5. Spastic pes planus. This type of foot was readily recognized by fixed pronation of the heel, little or no subtalar motion, spasm of the peroneal muscles, and absence of roentgenographic evidence of arthritis. Serious disability was the rule, and hospitalization was usually necessary, but no treatment could fit a man with a foot like this for full military duty.

There was much to be said for the suggestion of Capt. Arnold D. Piatt, MC (*14*), 127th Evacuation Hospital, Camp Bowie, Tex., that when flat foot was encountered, structural and clinical characteristics be disregarded and it be designated simply as pes planus, symptomatic or asymptomatic. After all, that distinction was all that was necessary for medical military purposes. If something more was desired, then Captain

Piatt suggested that the scheme of measurements devised by Morton (*15*) be universally adopted.

Clinical considerations.—All metatarsal heads normally rest on the ground during weight-bearing. Because of the differences in the shapes of the metatarsals, however, the transverse arch present on the plantar surface of the foot behind their heads varies in height, though there is no relation between these variations and symptoms referable to the feet. The wartime experience showed that metatarsalgia could result from improper distribution of the body weight through the metatarsals to the ground in either standing or walking, but that this manifestation was not associated with changes in the transverse arch.

When the dispensary surgeon encountered a patient with pes planus, his principal responsibility was to determine the extent of the functional disability; the degree of deformity was secondary. The history was likely to reveal that the condition had existed as long as the patient could remember. Symptoms and complaints included swelling of the feet on walking and marching, limitation of joint motion, and bulging on the medial aspect of the foot. The bulging represented the head of the talus, which was twisted medially and downward. The result was poor articulation with the tarsonavicular, and valgus of the entire forefoot.

Examination of the feet revealed loss of the normal contour of the inner longitudinal arch, an apparent increase in the size of the navicular bone, a compensatory increase in the prominence of the medial malleolus, abduction of the forefoot, eversion of the heel, often shortening of the Achilles tendon with limitation of the range of dorsiflexion, and frequent restriction of the range of motion in the subtalar and midtarsal regions. Major Sutro (*8*), whose observations were based on 220 carefully studied cases at Fort Riley, Kans., called attention to the points of tenderness elicited by palpation over the metatarsal heads, the plantar fascia, and the course of the posterior tibial tendons. Occasionally, a concomitant spasm of the peroneal muscles caused fixation of the foot, with complete absence of passive midtarsal and subtalar movements.

Roentgenologic observations.—Roentgenologic examination in the standing position showed loss of the normal dorsal tilt of the calcaneus. The bone tended to assume a rectangular, rather than its normal downward, tilt. The examination also showed a downward tilt of the astragalus, with compensatory diminution in the equinus attitude of the first metatarsal bone, secondarily compensated for by downward tilt of the proximal phalanx of the big toe, with a resulting phantom dorsal bunion at the metatarsophalangeal area.

Associated conditions.—Some flat feet showed really serious associated conditions, which fully explained the men's complaints. In some cases, there was incongruity of the articular surfaces of certain bones. Eversion of the os calcis, for instance, could produce minimum traumata to its articular surface, with resulting fibrillation and degeneration of the oppos-

ing articular cartilages. Similarly, the downward and inward tilt of the astragalus could cause the medial half of the head to fail to articulate with the navicular bone. The affected portion of the head in time degenerated, became fibrotic, and served as a basis for premature osteoarthritic changes. Other joints of the foot showed similar changes. There was no doubt that ligamentous structures, such as the plantar fascia and the long tendons, acting as slings on the plantar aspect of the foot, also underwent trauma and showed premature degeneration akin to that seen in the long head of the biceps in the aged.

Management and results.—The therapy of symptomatic flat foot was extremely difficult and unsatisfactory. Good results were occasionally achieved with whirlpool baths, ordinary or special arch supports, and elevations of the heel. Temporary correction was sometimes possible by mild manipulation or arrangements to bear weight on the outer aspects of the foot, so that the unduly prominent medial malleolus assumed its normal relations and appeared of normal size. Exercises were prescribed to teach the patient how to walk correctly. They were contraindicated if osteoarthritis was present.

One of the difficulties of managing soldiers with pes planus was the provision of special shoes, which is discussed in a separate chapter (p. 781).

What all of this amounts to is that there was no certain method for transforming a flat foot into a normal foot and making the owner a combat soldier. Moreover, whatever method was adopted kept the man's attention concentrated on his feet and created, or increased, the neuropsychiatric element present in many cases. A great many soldiers knew that extreme flat foot did not meet induction standards, and if they wanted to escape service, or if their assignments were undesirable, they tended to exaggerate their disability and use it as an excuse for getting out of the Army.

Pseudo pes planus.—Major Sutro (*8*) called attention to 14 cases of what he termed "pseudo pes planus" (fig. 178) observed at the regional station hospital at Fort Riley as the result of an increase in subcutaneous fatty tissue in the region of the inner longitudinal arch, with resulting complete obliteration of that arch. The excess layers of fat could easily be mistaken for a bony protuberance. Symptoms were scanty if they were present at all, but the patients were disturbed by the appearance of their feet. Examination invariably confirmed the absence of pathologic changes. The range of motion of all the joints was normal. There was no evidence of restriction in the active power of the evertors and invertors of the foot. The Achilles tendon was of normal length and did not interfere with the arc of dorsal and plantar flexion. Roentgenograms made in the standing position revealed normal dorsal tilting of the calcaneus and a normal angle between it and the cuboid bone. The excess of subcutaneous fat, which was the only abnormality present, showed up as a soft tissue mass in the midtarsal region.

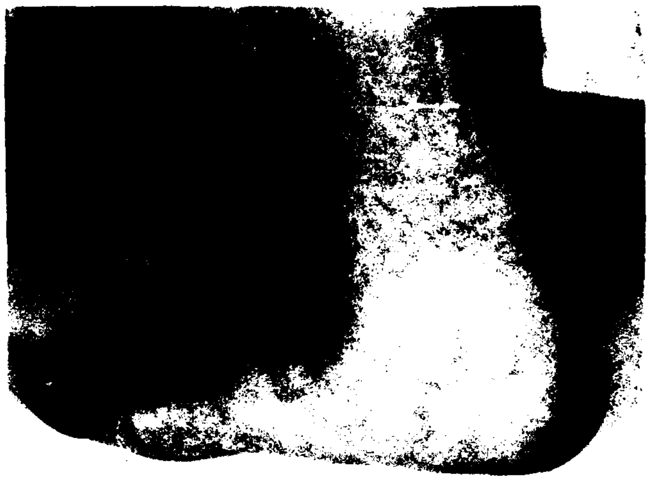

FIGURE 178.—Pseudo flat foot. Note increase in subcutaneous tissue in region of inner longitudinal arch. (Sutro, C. J.: Disabilities of the Foot Other Than Those Incurred by Training. [Unpublished data.])

Other Conditions

Separation from service on Certificate of Disability for Discharge was undoubtedly the solution of many cases, but it was a solution that in itself created problems. A great deal of discussion was devoted to it at the 1943 Army Air Forces conferences (*5*), for obvious reasons: At one camp which reported, 70 CDD's had been given for this cause in a single week. In another, 70 out of 200 CDD's were for this cause. In contrast, it was reported that not a single CDD had been given for pes planus in the Regular Army between 1935 and 1940. A number of the participants in the discussion agreed that all men who complained of symptomatic pes planus should be screened to rule out neuropsychiatric causes (conversion neurosis). Others were inclined to sympathize with the statement of a former medical officer in the German Army that, in that Army, no attention was paid to complaints referable to pes planus.[4]

Arthritis.—It was extremely important that an arthritic foot be recognized when the candidate for induction was first seen. A history of recurrent episodes of stiff, painful, swollen feet was an indication for a detailed investigation. An apparent etiologic factor could sometimes be elicited, such as an injury (figs. 179 and 180) or gonorrheal arthritis, or a typical history of generalized arthritis might be secured. Characteristic

[4] Obviously, the surgeons in the U.S. Army paid far too much attention to pes planus and wrote too voluminously about it.—*M. C.*

FIGURE 179.—Lateral roentgenogram of right foot showing many small shot, the result of a gunshot wound (bird shot) 3 years earlier. Note traumatic arthritic changes. This man had a utilizable skill and was, therefore, retained in the Army. (Breck, L. W.: Orthopedic Problems in Troop Training. [Unpublished data.])

findings were limitation of joint motion and pain at the extremes of the range of motion. Other findings included tenderness, swelling, local heat, arthrosis, characteristic roentgenologic changes, and an increased sedimentation rate.

If a man with arthritis of the feet was inducted during a period of quiescence, activation was likely during the first few weeks of training. It was unwise to induct such a man into service, and equally unwise to keep him in service if he had been inducted through an error of judgment. Once the joints of a foot had been damaged by arthritis, the prognosis for full military duty was extremely poor (*16*).

Bursitis.—Painful bursae, or a combination of bursitis and exostosis on the dorsum of the foot, could usually be relieved by wearing longer shoes and using a soft felt pad over the affected area under the tongue of the shoe.

Plantar neuroma (Morton's toe).—Morton's toe (metatarsalgia, so called long before the pathologic process was understood) was a diagnosis that had to be kept in mind because the condition was occasionally encountered. It was sometimes, but not always, preceded by injury. These plantar neuromas were correctible by early excision.

Hyperkeratoses and plantar warts.—Most multiple painful hyperkeratoses were of congenital origin and were observed chiefly in Negroes. They were characterized by thick, tender calluses over the lateral and posterior aspects of the heel, along the medial aspect of the first metatarsal phalangeal joint and the great toe, under the metatarsal heads, and at other points of continuous irritation and weight-bearing. Treatment was not

FIGURE 180.—Lateral roentgenogram showing longstanding traumatic osteoarthritis of talonavicular joint. This patient was seriously disabled and was discharged from the Army as he had no skills that could be utilized in a limited duty assignment. (Breck, L. W.: Orthopedic Problems in Troop Training. [Unpublished data.])

satisfactory, and men with these lesions were considered disqualified for full military service.

The management of plantar warts with radiation is discussed in detail in the volume on radiology in this historical series (*17*). Other successful methods of treatment, which were far simpler, included shaving, the application of salicylic acid crystals to remove the calloused skin, and the repeated application of strong tincture of iodine.

Achillodynia.—Pain and discomfort in the Achilles tendon (achillodynia) ranged from painful irritation to true tenosynovitis. It was usually caused by transition from the low shoes of civilian life to GI shoes and by the unaccustomed amount of walking and marching. The constant pressure of the military shoe caused pain and tenderness, which increased with every step taken. Achillodynia was most frequent among fresh troops in training or among those who returned to hiking after periods of relative inactivity. A rough, uneven terrain was also a factor.

Examination might be entirely negative except for localized tenderness or might reveal reddening, swelling, and crepitation on movement. A

number of patients with achillodynia observed at Camp Maxey, Tex., showed myositis ossificans in the related muscle belly (*18*).

The patients with achillodynia were almost without exception new recruits with acute conditions, who could be treated satisfactorily because trophic changes had not yet set in. Two techniques were employed:

1. The painful areas were sprayed with ethyl chloride until frost appeared, then gently massaged with liniment until the skin was warm. The ankle was moved in all directions, to be certain that all painful areas were treated. Immediately after this session, the soldier was instructed to walk vigorously. Success in large measure depended upon this phase of the procedure.

This method was used in 14 consecutive cases of achillodynia at the A. P. Hill Military Reservation, Bowling Green, Va., with immediate marked to complete relief. All the men were able to return to duty at once, and during the few days of observation possible there was no recurrence of the difficulty in any instance.

2. This method, devised by Capt. Paul J. Reinsch, MC (*19*), 104th Infantry Division, involved strapping the foot in such a manner as to relax the Achilles tendon. Three long 1-inch strips of adhesive tape ran from the metatarsal arch over the heel to the middle of the posterior calf. They were anchored by four short crosspieces applied over the ball of the foot and heel and above the ankle and the calf. Tincture of benzoin had previously been applied to the skin. The strapping was carried out with the foot in moderate extension, the heel 1 inch off the ground, the ball of the foot touching the ground, and the leg perpendicular. The patient was cautioned to step gingerly for a few minutes, to allow the tape to stretch, and to lace his shoes only to the third eyelet from the top, to eliminate some of the factors which had caused the original disability. The tape was left in place for 3 to 4 days and seldom had to be replaced since relief with this method was immediate.

At Camp Maxey, a small number of shortened heel cords were observed, caused by the habit of Texas men and boys of wearing cowboy boots with high heels all their lives. The practice made it difficult for some of them to wear the regular GI shoe with low heels.

Ingrowing toenails.—Ingrowing toenails (onychocryptosis) were compatible with acceptance for military service (p. 738). They were, however, a source of annoyance and worse, whether they occurred in men inducted with them or developed after induction. Manifestation varied from simple irritation along the lateral nail fold of the great toe to advanced cellulitis and suppuration, with occasional lymphangitis. In the chronic stage, which was frequently observed, the presence of granulation and heaped-up crusts along the nail edge usually indicated treatment and recurrences over protracted periods of time.

Treatment ranged from palliative attempts at elevation of the nail with small wedges of medicated cotton to radical excision of the entire nail, the root matrix, and the paronychium. The latter technique required a needless sacrifice of tissue and a prolonged convalescence.

A simple, quick, and very effective surgical procedure (fig. 181) was devised by Capt. Frank B. Whitesell, Jr., MC (*20*), and performed with a shark-fin type of onychotome which he also devised himself.

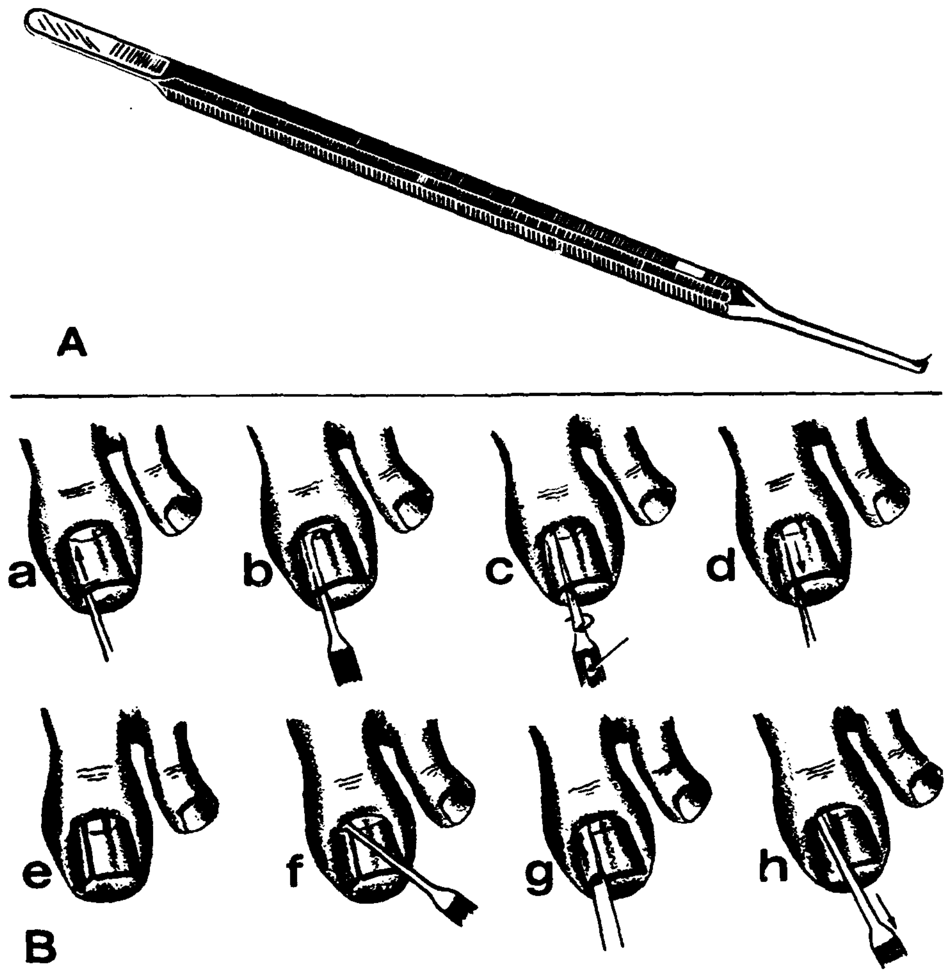

FIGURE 181.—Removal of ingrowing toenails. A. New shark-fin onychotome with double cutting edge blade. B. Details of technique: Insertion of instrument beneath nail (a, b), rotation of blade to vertical position (c), withdrawal of instrument and splitting of nail (d, e), separation of eponychium (f), separation of segment to be removed from nail bed (g), and curettage of nail matrix (h). (Whitesell, F. B., Jr.: A New Instrument and a Simplified Technique for the Cure of Ingrown Nails. [Unpublished data.])

After nerve block about the base of the involved toe, the instrument was inserted beneath the nail proximally, with the blade parallel to the nail, until the blade was under the eponychium. It was then rotated to a vertical position and the point was forced upward through the nail. As the instruction was withdrawn, the nail split evenly and cleanly. The eponychium was then freed from the segment to be removed, which was freed from its bed with the opposite (spatula-like) end of the instrument. Finally, the blade was used to curette the matrix.

In no instance was it necessary to excise a wedge of paronychium. The operating time, after anesthesia was accomplished, was only a few

minutes. There was little or no bleeding in spite of the omission of a tourniquet.

Postoperative care consisted of application of gentian violet and dusting with sulfanilamide powder whenever the dressings were changed.

Removal of the irritating nail edge was soon succeeded by subsidence of the inflammatory process and prompt disappearance of crusts and granulation tissue. In a few instances, this process was expedited by the use of hot soaks with epsom salts for a few days.

There were no failures in 25 consecutive operations in which this technique was used, and most of the men were ready for duty within 24 to 48 hours.

Two structural aspects of the nail facilitated the use of this technique:

1. The nail proximal to the lunula is membranous and lacks the hard, horny character of its more distal portion, so that it could be perforated readily from below by the point of the instrument.
2. The longitudinal striations of the nail made it simple to split or cleave the nail in this direction with slight distal traction.

Posttraumatic adhesions.—A painful foot might follow any sort of trauma that caused prolonged swelling. The adhesions responsible in many such cases limited joint motion and increased pain when an attempt was made to force the joint to move. Diagnosis depended upon a history of trauma, limitation of motion, and absence of clinical and roentgenologic evidence of arthritis.

Manipulative therapy was more successful in this condition than in other foot disabilities. It was done gently, under general anesthesia, with as much stretching and as little tearing as possible. All the joints were put through the full range of motion, even if two or three sessions were necessary to accomplish the desired results. If multiple sessions were required, at least 3 weeks elapsed between them. If ecchymosis, swelling, or other manifestations of a severe reaction appeared, it was assumed that the treatment was accomplishing more harm than good. If the foot was very stiff and the joints appeared bound down, manipulations were undertaken tentatively, without expectation of much improvement. In successful cases, the patient was ambulatory the day after manipulation and, if he kept his foot active, could usually return to duty within 10 days.

Special cases.—At the 186th General Hospital, while it was in the Zone of Interior, three patients were observed with much the same symptoms and signs. The chief symptom in all three cases was metatarsalgia affecting the second, third, and fourth metatarsal heads. The feet were weak and pronated. The first metatarsal tended to be short, and there was apparent drooping of the middle metatarsal head, with thick callus underneath it. Mild pes cavus was also present. Relief was affected by use of a well-fitted, high, wide metatarsal pad of felt or firm sponge rubber glued to the inside of the shoe or fastened to an insole that could

be inserted into any shoe. It was so placed that the body weight was borne on the shaft of the affected metatarsal bone and not on its head.

A number of unusual cases were studied by Major Sutro (*8*) in his analysis of lesions of the feet at the station hospital at Fort Riley:

1. A patient with a nonspecific unilateral infection of the os calcis, just at the insertion of the Achilles tendon, could not bear weight on this area, which was persistently red and tender. No clinical or roentgenologic evidence suggested gout, and no infection could be demonstrated in any system. Roentgenologic examination revealed a large zone of increased density and resorption at the periphery of the posterior portion of the os calcis.

2. Three patients presented Freiberg's infraction (osteochondritis of the head of the second (and less often the third) metatarsal). The complaint in each instance was the same, pain on weight-bearing and inability to pursue routine military duties. Examination showed an abnormal prominence on the dorsum of the metatarsophalangeal articulation of the involved toe. Pressure over it caused pain and discomfort. Roentgenograms showed that the bones comprising the affected joints were irregular in contour and considerably wider than normal. One or more bony ossicles were present within the articular cavity. Metatarsal pads and bars gave only temporary relief, and surgical resection of the head of the affected metatarsal bone, with resection of the base of the contiguous proximal phalanx, was regarded as the only feasible treatment.

3. A patient with persistent pain over the great toe was found to have an avascular necrosis of one of the sesamoid bones over the metatarsophalangeal articulation. There was moderate limitation of motion at the articulation, and localized tenderness on the plantar aspect of the affected sesamoid bone. A history of old direct injury in civilian life was obtained. Roentgenograms of the great toe, with an axial view of the involved articulation, revealed increased density of the fibular sesamoid bone, the contour of which was slightly irregular. Little relief was secured from metatarsal bars and pads, and surgical removal of the affected bone was refused.

Section II. Combat-Incurred Lesions

GENERAL CONSIDERATIONS

Most patients with combat-incurred wounds of the feet were received in Zone of Interior general hospitals between 4 and 8 weeks after they had sustained their injuries. They had been treated overseas by the general routine of resuscitation, initial wound surgery, and immobilization described in the volumes of this series dealing with orthopedic care in the Mediterranean and European theaters (*21, 22*), and they were received in

what might be termed the "intermediate stage of injury." None of them needed emergency care on their arrival in the Zone of Interior and time could be taken to decide upon and carry out individual management, on the general thesis that a living foot, with reasonable stability, sensation, and comfort, even though it might be seriously deranged, was always more desirable than a prosthesis. Very few amputations were necessary in Zone of Interior hospitals.

On the whole, the patients arrived in good general condition. Early in the war, wounds were packed open. Later, most of them had been closed overseas by delayed primary wound closure. Infection of the soft tissues was present in some cases, and osteomyelitis in others. In some cases, the wounds were healed, but plastic surgery on the soft tissues was necessary before definitive surgery could be undertaken.

Ideally, the cast bore essential data, including the type and location of the injury; the dates on which it was sustained, on which operation was done, and on which the cast had been changed serially and for the last time; and the status of the wound. All of the patients had had sulfonamide therapy or, after its introduction, penicillin therapy.

INITIAL EXAMINATION

The routine of management of combat-incurred wounds of the feet was carried out in general hospitals in the Zone of Interior more or less as it was employed at Valley Forge General Hospital, Phoenixville, Pa. (*23*). The initial examination covered the following points:

1. Circulation. Circulatory difficulties were few at this stage of the injury, though careful observation of swelling and other reactions was still necessary. Amputation for circulatory reasons was practically always an overseas procedure.

2. Nerve injuries. Injuries to the nerves within the foot caused only a partial loss of sensation on either aspect or under the sole and seldom altered the functional outlook. Nerve lesions higher up in the leg, however, had more important and more serious implications and might change the whole picture of future usefulness of the foot.

3. Soft tissues. The loss of skin and soft tissues was often a serious phase of injuries of the foot and required correction as soon as possible.

4. Bones and joints. Even when their previous roentgenograms accompanied the patients, as ideally they always did, fresh examinations were made, preferably with the feet out of plaster, to visualize details of the bony injuries and to determine the present state of healing and alinement. Routine views of the foot and ankle were usually satisfactory, but special angles were occasionally necessary. Orthopedic surgeons who treated wounds of the foot required a precise knowledge of the normal shapes and positions of all its bones and had to develop the habit of analyzing all joint contours before undertaking any surgery.

PRELIMINARY MANAGEMENT

With the information just listed at hand, a plan of treatment was laid out for each patient for his immediate and his definitive care. Often the plan included reconstructive surgery, though the foot was always given a test of time and use before such surgery was instituted. In a surprising number of instances, operations that at first seemed inevitable later proved unnecessary.

The primary objective of treatment of wounds of the foot in the Zone of Interior was to secure a painless, weight-bearing foot, which would permit the patient to live a useful life. The strain of conducting the body weight through every step of the day is difficult for deformed and distorted bones and joints. Yet nature has remarkable healing powers, especially in the strong-muscled youthful group that comprised most of these patients, and many of them recovered entirely capable feet.

Painless weight-bearing was the first goal of treatment. Flexibility of the foot was secondary. A painful joint was always more disabling than a stiff joint. Fortunately, the natural arrangement of the human foot involves an abundance of joints, one or more of which may be sacrificed without causing serious disability.

As soon as the cast was removed, the foot was soaked and the wounds cleansed in warm, soapy, sterile water. Sinuses were probed and irrigated. Loose or exposed pieces of bone and foreign material were removed. The wound was dressed with a layer of small-mesh, petrolatum-impregnated gauze, overlaid with sterile gauze dressings. The original practice of dusting the wound with sulfonamide powder was later discontinued.

Positioning of the foot before the cast was reapplied was carried out with great care and precision, for it often determined future stability. As a rule, the foot was placed in normal weight-bearing alinement, in slight valgus or in eversion, under the tibia, with the ankle joint at 90 degrees. The os calcis was placed in either direct alinement or slight inversion. The contour of the foot and arches was molded to as near normal relations as possible before the plaster was applied. Only an essential amount of padding was used, so that the cast would provide close support. How often the cast was changed depended upon the patient's comfort, the type of injury, the presence and amount of discharge, and similar matters.

Skin defects were covered and open wounds closed as soon as possible, preferably on the plastic surgery service. Split-thickness skin grafts were usually successful. Deep, tense scars, which were likely to be painful and which militated against good end results, were freed from deep fascia and tendons, and the resulting raw surfaces were covered with skin grafts.

Once the skin and soft tissues were healed, a period of weight-bearing was instituted in all cases in which it was practical, to determine whether or not pain was present on ambulation and to detect exact structural weaknesses. At first, it was best to keep the foot elevated frequently, but

when this period had passed, a walking iron or caliper was added to the cast. When rigid support was no longer necessary, a flexible Unna's gelatin boot or an elastoplast bandage frequently was substituted for plaster.

Ambulation, introduced at the right time in convalescence, had numerous advantages. The circulation, and consequently the appearance, of the foot promptly improved with weight-bearing and exercise. The decalcification of disuse was reversed, and bone density began to gain. Points of stress promptly became apparent, and roughened joints became painful. These observations were correlated with roentgenologic examinations, which revealed structural weaknesses, joint sclerosis, irregularities, bone deficits, fragments of bones, and other bony damage. Particular attention was paid to the weight-conducting structures that were damaged or missing.

As soon as weight-bearing in a properly fitted shoe was practical, the patient was tested to determine what nature could do to restore painless weight-bearing and normal walking. A Thomas heel and metatarsal bar were used, to take some of the pressure off the forefoot, and to add an element of stability and control. Even in a properly fitted shoe some sort of support was frequently needed, because muscles and ligaments were weak from their long period of disuse, and strain could develop, particularly in the longitudinal arch. Pressure points in the shoe also had to be eliminated. During this period, the patient was watched carefully, and a correct gait was insisted on. Most patients were eager to be ambulatory and cooperated well in testing their ability.

At this stage in the program, management in wounds of the foot was based on three premises:

1. Walking is the best physical therapy for an injured foot.
2. A patient cannot walk on either a swollen foot or a foot not adequately supported by a shoe.
3. Swelling can be prevented by competent elastic protection and can be relieved by elevation and exercise.

While walking, as just indicated, was the most desirable and most effective means of rehabilitation, physical therapy was also a decided help. The crusted foot, with dry skin, just out of a cast, was benefited by oil massage and whirlpool baths. The foot contracted by scar tissue was helped by the softening effect of whirlpool baths and by manipulation. Training in walking was important, and the physical therapist set the proper patterns. Wounds that healed sluggishly were often benefited by infrared light. Foot exercises in a well-equipped gymnasium were also used extensively.

The effects of the physical therapy techniques used had to be watched carefully. They were not always beneficial. Some extremities, for instance, became increasingly swollen from the dependency required in whirlpool baths. In such cases, dry heat applied while the leg was horizontal was decidedly better.

Time and testing were necessary in many wounds of the foot before a complete evaluation of the probable outcome could be made. In some instances, the decision for and against surgery had to be delayed for many months. During the period of observation, a number of special factors had to be considered:

1. Accurate localization of the injury and determination of its residua, to identify the exact cause and source of any pain or discomfort. When a foot was swollen, stiff, and painful in every area, it was difficult to establish the origin of the trouble. The swelling had to be eliminated before individual joints could be checked. When lateral motion of the heel was painful, for instance, irritation and irregularity of the subastragalar joints had to be considered. The amount of motion each joint was capable of also had to be determined. The gait was carefully analyzed, and the line of the weight thrust down the leg and into the foot was checked as the patient moved along. Comparison with observations on the intact foot was always useful and frequently imperative.

When weight-bearing was painful enough to cause a serious limp, particularly on rough ground, and when it prevented the patient from walking 2 or 3 miles or engaging in his usual occupations, an attempt was made to ascribe the difficulty to a single cause. If corrective measures did not improve the situation, then reconstructive surgery was undertaken, the procedure depending upon the nature and location of the injury.

2. *The character and disposition of the patient.* It was not always possible to tell from the type and extent of the injury or from the roentgenographic findings what the result of surgery would be in the individual case. It was necessary to weigh the patients' cooperation; to determine whether they were making a real effort to walk normally (as most of them were); to evaluate their tolerance for pain; and, in some cases, to estimate the importance of psychoneurotic factors. Patients with self-inflicted wounds required particularly careful evaluation before surgery was undertaken.

REGIONAL INJURIES

The Tarsonavicular Bone

Damage to the tarsonavicular bone, with resulting deformity extending into the astragaloid or the cuneiform joints, could cause disabling pain if it was in the line of the direct weight-bearing thrust. In some instances, fusion was accomplished across the astragaloscaphoid joint by means of a small inlay graft from the inner lip of the scaphoid:

Case 1.—This patient sustained a gunshot wound of the foot from his own rifle in North Africa in March 1943, with loss of most of the scaphoid. Fusion of the space between the astragalus and cuneiform bones was accomplished with bone grafts from the tibia (fig. 182).

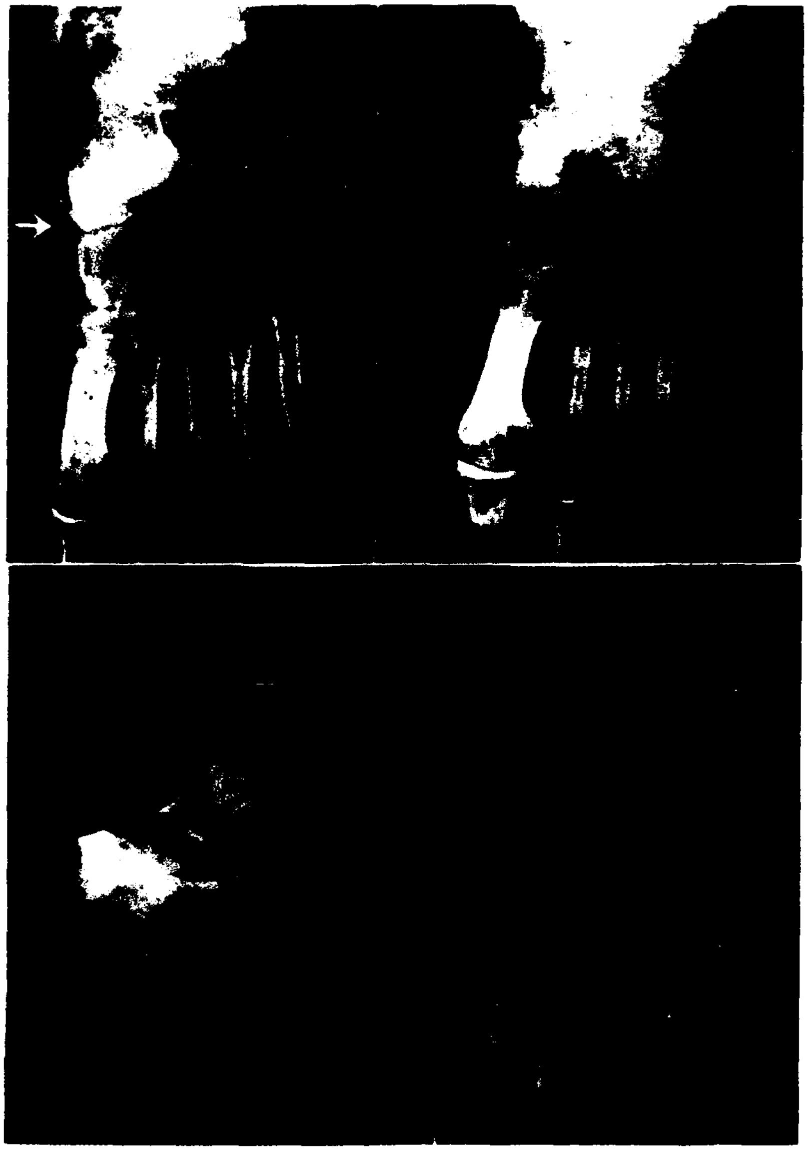

FIGURE 182.—Gunshot wound (self-inflicted) of foot. (Top) Oblique and anteroposterior roentgenograms of left foot showing considerable loss of substance of tarsal scaphoid and disruption of astragaloscaphoid and scaphoid-cuneiform joints. (Bottom) Lateral and anteroposterior roentgenograms of same foot after stabilization had been accomplished by tibial bone grafts extending from astragalus to cuneiform bones, with resulting midtarsal arthrodesis. (Snedecor, S. T.: J. Bone & Joint Surg. 28: 332–342, April 1946.)

Results in cases of this type were generally good. When a considerable loss of substance of the scaphoid had occurred, or a distortion of the astragaloscaphoid talonavicular joint was the result of injury, the calcaneocuboid joint was evened up in substance and triple arthrodesis

was completed. In properly selected cases, the results were reasonably good.

The Cuboid

In a combat injury of the outer aspect of the foot with involvement of the cuboid and its joints, there was usually so much destruction in the calcaneocuboid joint that only triple arthrodesis could be considered. In two or three such cases handled at Valley Forge General Hospital, an added complication was the loss of bone between the remnants of the calcaneus and the cuboid. If the scaphoid bone had been removed, or if the astragalus had been shortened to bring the foot into line, the foot would have been seriously shortened. As an alternative, bone grafts were used to bridge the defect:

Case 2.—This patient sustained a gunshot wound of the foot from his own rifle in a foxhole in North Africa in March 1943, with a serious defect in the calcaneocuboid articulation. Fusion of this articulation with a bone graft bridge produced reasonably good results.

In two other cases also observed at Valley Forge General Hospital, the navicular and the cuboid were blown out in a wound across the foot. After healing of the soft tissues, each patient was left with a flail forefoot and each walked on his heel, almost as if the forefoot was missing. At operation, after scar tissue had been dissected out, the remainder of the joint cartilage was removed, and the bony remnants were beveled off and matched together. The cuneiform bones and part of the cuboid of the forefoot were brought into apposition with the astragalus and the calcaneus. Fusion was accomplished, and the end result in each case was a much foreshortened, but reasonably painless and stable foot (fig. 183).

The Cuneiform Bones

It was uncommon for any of the cuneiform bones to be injured alone. Injuries to them, which occurred in crushing as well as in combat injuries, were frequently associated with injuries of major bones. Injured cuneiform bones sometimes fused spontaneously with each other, or with the bones ahead of or behind them. If a firmly fused mass of bone ensued, a useful foot resulted. Persistent bone defects were sometimes associated with localized pain. In these cases, fairly good results were achieved by curetting the cavities and filling them with bone grafts from the tibia:

Case 3.—This patient had a self-inflicted wound sustained in North Africa in January 1943. As so often happened in such injuries, a painful traumatic arthritis resulted from destruction of the middle cuneiform bones. Fusion was accomplished with a bone graft.

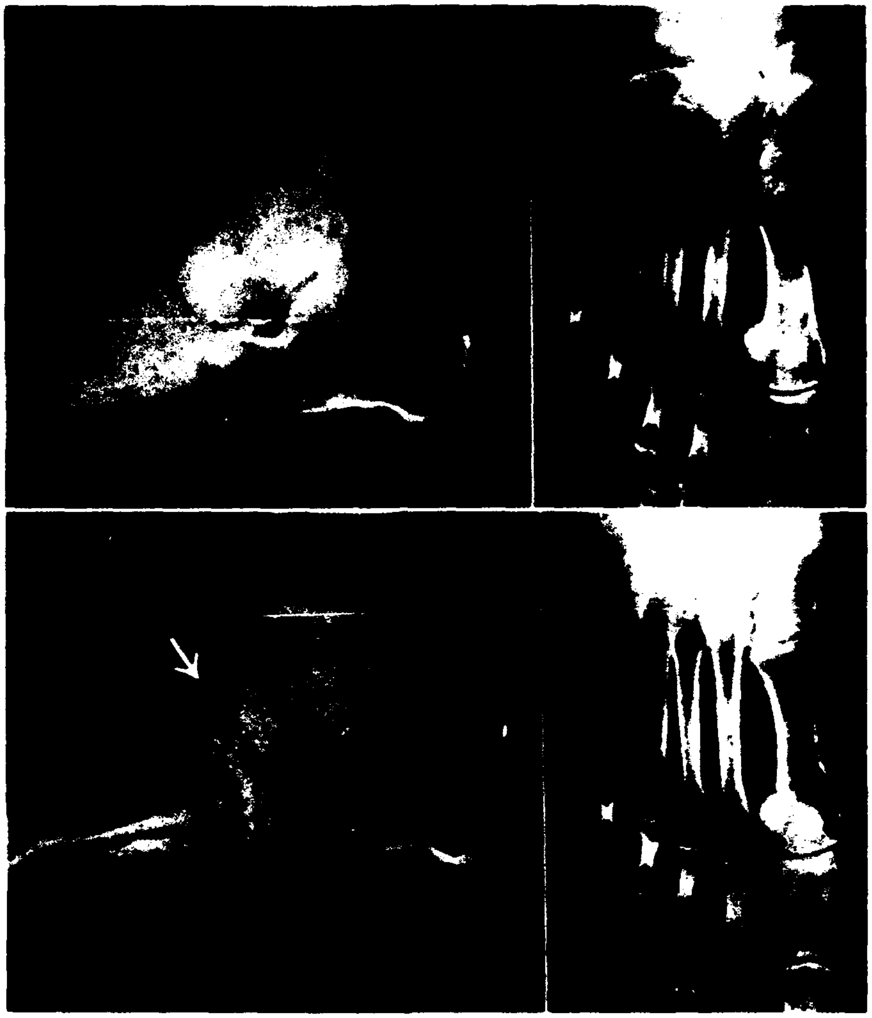

FIGURE 183.—Shell wound of foot sustained in Normandy in July 1944. (Top) Lateral and anteroposterior roentgenograms of foot showing marked disruption of mid tarsus with considerable loss of substance of scaphoid and cuboid bones. (Bottom) Lateral and anteroposterior roentgenograms of same foot after midtarsal fusion had been accomplished to stabilize a somewhat shortened forefoot. (Snedecor, S. T.: J. Bone & Joint Surg. 28: 332–342, April 1946.)

The Metatarsal Bones

Multiple injuries of the metatarsal bones usually left a painful residual foot, the treatment of which presented many problems. If there was loss of substance in the first or second metatarsals, bone grafts were used to correct the defects (fig. 184). Gaps in the second and third metatarsals were usually left unfilled. In a case observed at Valley Forge General Hospital, the big toe had been amputated from beyond the anterior third of the first metatarsal, leaving the posterior two-thirds of the metatarsal

FIGURE 184.—Gunshot wound (self-inflicted) of foot. This soldier was wounded "while asleep" by his own rifle in the South Pacific in August 1943. Anteroposterior and lateral roentgenograms of left foot showing fractures of first, second, and third metatarsal bones. The considerable loss of substance in the first metatarsal has been bridged by a tibial graft.

without support except at the base. The anterior end of the first metatarsal was anchored across to the second with a bone graft.

Deformities of the metatarsal heads which caused pain were usually corrected by cautious, but generous, resection of offending spurs or bumps. If the whole head had to be resected, the shaft was also resected well back toward the base. Deep scars in this area could be very troublesome.

In instances of localized arthritis of a proximal joint, fusion gave satisfactory results in very carefully selected cases. Operation was not undertaken until after a fair trial of conservative measures, such as shoe modifications with a metatarsal pad or the use of other special supports to relieve pressure on painful joints.

The Toes

If the joint surface of the proximal phalanx had been badly damaged, traumatic arthritis was a likely consequence, with limitation of dorsiflexion, rigidity of the hallux, and persistent pain (*17*). The treatment of choice was resection of the base of the first phalanx by the Keller technique. If the distal joint was involved, the joint surfaces were curetted to encourage

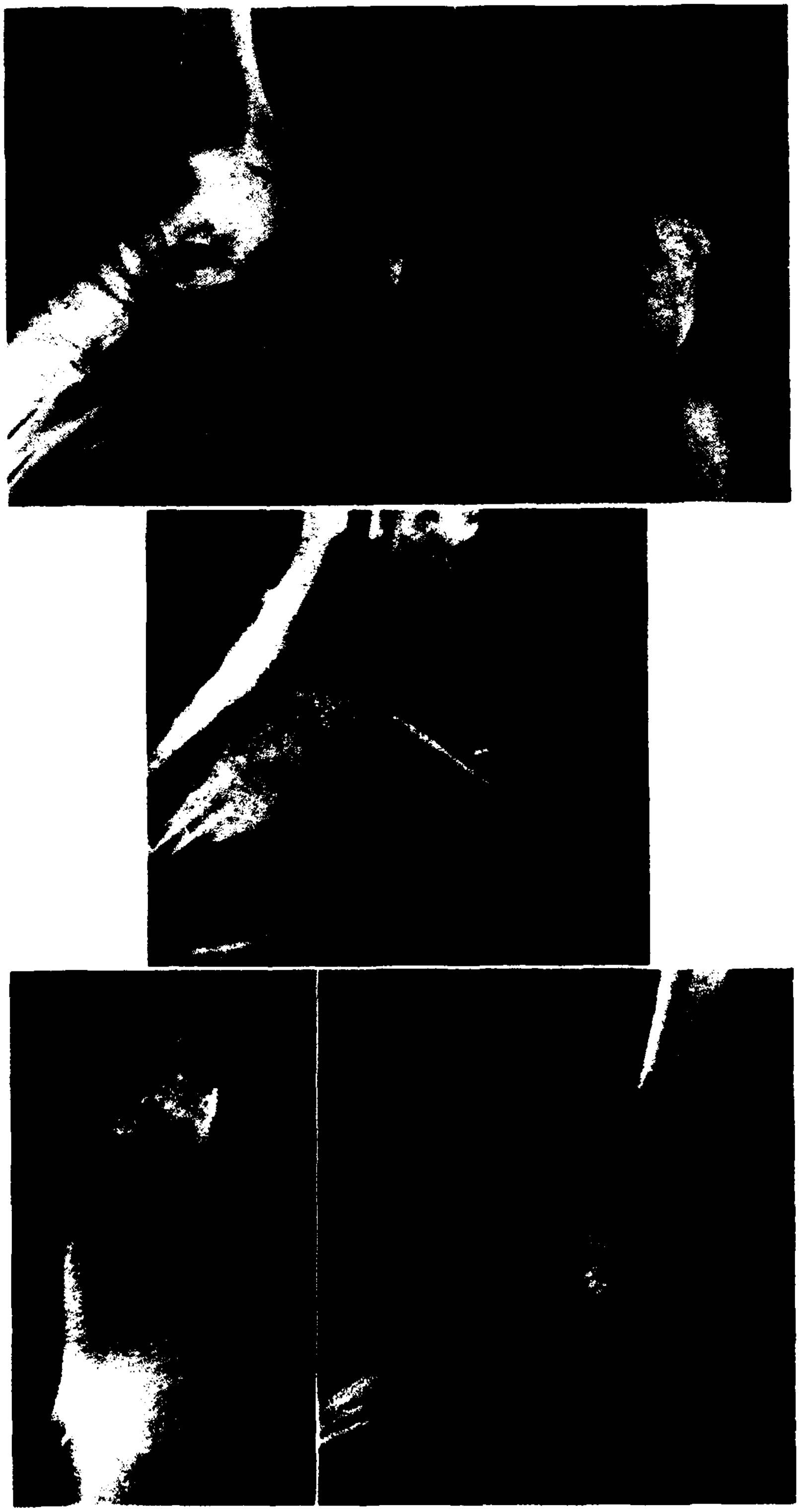

FIGURE 185.—*See opposite page for legend.*

them to fuse. If the source of pain was a handicapping sensitive scar, the end of the toe could be partially amputated, to secure enough good skin to cover the scarred areas.

If the little toe was badly damaged, some orthopedic surgeons believed that the effort expended, the long convalescence, and the doubtful results of reconstructive surgery, made early amputation the preferred method of management. This was not the general opinion.

The Os Calcis

When active fighting began in overseas theaters, compound fractures of the os calcis were seen in large numbers as the result of landmines. The accompanying soft-tissue and vascular injuries were often severe and limited the possibilities of early remodeling of the contours of the shattered heel. The situation was often further complicated by multiple associated fractures of the metatarsals, the astragalus, and the tibia and fibula.

These injuries were problems overseas and problems in the Zone of Interior. Cancellous bone, of which the os calcis is composed, does not have much resistance to infection, and the result of surgery was often serious deformity because of the amount of bone that had to be removed to eradicate the infection. Many an orthopedic surgeon speculated, in retrospect, whether in a given case it might not have been better to resort to amputation promptly and thus avoid the prolonged, complicated, and often unsuccessful surgery that was the alternative.

At Valley Forge General Hospital, combat injuries of the os calcis were managed as follows (*23*):

1. Unreduced fractures were treated by open reduction as soon as the tissue reaction had subsided and soft-tissue wounds were healed. Operations were performed with two objectives: (a) To restore the general alinement and mold the fragments into as normal a contour as possible, and (b) to complete a triple arthrodesis:

Case 4.—This soldier was injured when the deck of a landing craft blew up during the invasion of Sicily in August 1943. He received a compound, comminuted fracture of the os calcis, which was unreduced when he was received in the Zone of Interior. The pull of the gastrocnemius had reversed the angle of the body by 45 degrees and what

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FIGURE 185.—Severely comminuted fracture of os calcis, sustained when submarine mine blew up deck of landing craft off Sicily in August 1943. (Top) Lateral roentgenogram of foot and roentgenographic view from above downward of heel, showing severely comminuted fracture of os calcis. Note dorsal tilt of larger posterior fragment. (Center) Lateral roentgenogram of same foot in plaster with Steinmann's pin holding the os calcis in corrected position by transfixing it to the talus. (Bottom) Roentgenogram of heel from above downward, showing the healed fracture of os calcis. Lateral roentgenogram of same foot after successful triple arthrodesis. (Snedecor, S. T.: J. Bone & Joint Surg. 28: 332–342, April 1946.)

FIGURE 186.—Arthritic changes in foot following shell wound sustained in Italy in November 1943. (Left) Lateral roentgenogram of foot showing arthritic changes in joint between talus and os calcis. (Right) Lateral roentgenogram of same foot after successful arthrodesis of talus to os calcis. The procedure eliminated the persistent pain experienced before operation.

was left of the fore part of the calcaneus was severely comminuted. At operation, even when the gastrocnemius was lengthened by 1⅛ inches, the deformity tended to recur. The body of the calcaneus was, therefore, fixed by a pin extending from it into the talus. The foot was put up in slight equinus and valgus (fig. 181).

In this case, and in similar cases, the outcome was fairly satisfactory when weighed against the severity of the injuries.

2. The painfully handicapped foot in which pain persisted after a test of weight-bearing was a major problem. The pain was most often located beneath the external malleolus, probably because of submalleolar widening of the calcaneal bulge. In a few cases, in which this widening seemed to be the sole cause of pain, simple gouging out of the bulge in the bone was followed by real improvement. In most instances, however, the source of the pain was clearly elsewhere, in the subastragalar, calcaneocuboid, or astragaloscaphoid talonavicular joints, alone or in combination. For simple traumatic arthritis in the subastragalar joint, without serious bone deformity, the Gallie operation was sufficient. An incision was made along the Achilles tendon, a slot was made in the posterior subastragaloid joint, and a tibial graft was inserted into the slot. For more serious deformities, the usual triple arthrodesis gave good results (figs. 185–187).

3. Infected comminuted fractures of the calcaneal body were frequent and difficult to treat. Infection found a ready entrance into the compound, splintered bones, and the resulting low grade osteomyelitis in the cancellous body of the bone required radical surgery:

Case 5.—This patient was wounded by shell fragments in North Africa in March 1943, sustaining a compound, comminuted fracture of the body of the os calcis. After three ineffective sequestrectomies, a radical saucerization was performed; the cavity was unroofed, and skin flaps were collapsed into it. Healing followed (fig. 188).

At Schick General Hospital, Clinton, Iowa, a troublesome group of persistent draining sinuses in the os calcis were treated by collapse of the central cavity (*24*). The sole of the foot was avoided and the necessary osteotomy was performed from within. The band of bone removed in the line of osteotomy, to mobilize one wall, was from one-fourth to three-eighths of an inch wide. The wall of the os calcis which was to be shifted was left attached to the soft tissue. When it was moved into approximation with the intact wall, it was held in place with a screw that transfixed the skin and both approximated walls.

This procedure was apparently permanently successful in six of eight carefully selected patients with intractable defects in the os calcis. Both failures occurred in very severe wounds, in which the technique described was used as an alternative to amputation.

Pain on weight-bearing, referable to the subastragaloid joint, was not at all uncommon in combat-incurred injuries of the os calcis. The explanation was the widening of the heel resulting from severe crushing forces extending into the facets of the subastragalar joint. The entire outer table of the os calcis, or a single large fragment, or, less often, several smaller fragments, came to lie before and beneath the tip of the fibula, in effect constituting a third malleolus. In these cases, the peroneal tendons were displaced, and manifestation of tenosynovitis not infrequently appeared over the outer aspect of the ankle and impeded the course of the tendons.

Routine fusing of the subastragalar joint gave good results, but if nothing else was done, the abnormal contours of the os calcis were left unchanged laterally. At Schick General Hospital, Maj. Joseph E. Milgram, MC, devised an ingenious procedure to narrow the os calcis in front of the fibula; remove the new third malleolus; recreate a comparatively normal lateral contour for the ankle; and free the peroneal tendons from the abnormal, often rough, prominences across which they had to pass.

In the first three cases in which this procedure was used, the desired narrowing was obtained by the usual method of simply chiseling away the expanded cortical prominences. The clinical results were good, but a rough defect was created, which was likely to become adherent later, and stout cortical bone was lost for fusion. In the next nine operations, a segmental osteotomy of the outer table was performed at the time subastragalar fusion was accomplished (fig. 189).

With a pneumatic tourniquet in situ, an incision was made in a lateral oblique direction from the anterior edge of the fibula to within three-fourths of an inch of the base of the fifth metatarsal. Dissection was carried down along the anterior edge of the fibula, superior to the

FIGURE 187.—*See opposite page for legend.*

course of the peronei, which were isolated and protected. The incision along the os calcis was carried subperiosteally by stripping away the tissue anteriorly as far as the calcaneocuboid joint ligaments. (Fusion of the midtarsal joints was considered necessary only if there was roentgenographic evidence of a fracture into one of them.) The peroneal tendons were retracted posteriorly, preferably with their sheaths intact.

After a standard triple subastragaloid (subtalar) arthrodesis, the lateral bulging cortex was reduced with a broad, thin osteotome. The outer table was divided in the frontal plane at two sites, one just in front of the fibula and the lateral ligaments of the ankle joint, and the other from three-eighths to one-half of an inch posterior to the calcaneocuboid joint. The chisel was driven inward a trifle less than halfway through the os calcis, down to the plantar cortex laterally. Next, room was provided for displacing the lateral table medially by excising a wedge of the cancellous os calcis one-fourth to one-half of an inch wide in the sagittal plane of the heel bone. The wedge was lifted out and preserved to use for later packing of the joint. The osteotome was driven horizontally through the lateral cortex at the end of the sagittal cuts, severing it incompletely. The outer table was fractured free by striking it with a board punch (a 6-inch segment of a ½-inch square steel rod was sawed off and plated to prevent its rusting in use). As the table was tilted inward and jammed in its new position, its upper edge rose to make contact with the freshened neck of the astragalus and afforded additional contact for fusion. No fixation of the new, compressed outer table was required. The sinus tarsi was thus recreated, and the lateral malleolus and peronei were freed.

Thin cortical shavings and cancellous bone were removed from the tibia, near the tubercle, through a 3-inch incision, and were packed into all joint interstices, especially at the facet sites. The scarred periosteum was closed with great care, with interrupted sutures of fine chromic catgut. The skin was closed with silk or cotton. A padded cast was applied and was at once split to allow for the spreading which frequently occurred.

In each of the nine cases in which this procedure was used, radiologic union was evident in about 4½ months, except for one gunshot wound, which broke down, though it eventually healed. During the approximately 5-month period these patients were observed, they were entirely free from

FIGURE 187.—Combined ankle and rear foot injury, with most of damage in foot, sustained by paratrooper from machinegun fire during invasion of Sicily. (Top) Anteroposterior and lateral roentgenograms, showing deformed remnant of lateral malleolus above bulge in lateral surface of talus. Fracture of os calcis is evident. (Center) Anteroposterior and lateral roentgenograms of same foot after removal of some of bony mass from lateral surface of talus. Calcaneocuboid disruption is more apparent. (Bottom) Lateral and anteroposterior roentgenograms of same foot after successful triple arthrodesis. The operation was requested by the patient after a long period of painful instability in this foot.

FIGURE 188.—Comminuted fracture of os calcis, following shell wound sustained in North Africa in March 1943. (Left) Lateral roentgenogram of foot showing comminuted fracture of os calcis with sequestra and obvious metallic foreign bodies. (Right) Lateral roentgenogram of same foot after unroofing of os calcis, radical saucerization of cavity, and adequate coverage with skin flaps. Spontaneous fusion has occurred between the astragalus and the os calcis.

midtarsal pain and were relieved of all symptoms referable to the subastragaloid and peroneal areas. In one case, an extensive exostosis had to be removed from the anterior tubercle of the os calcis, to facilitate painless weight-bearing. A cupped rubber heel was advised in all cases.

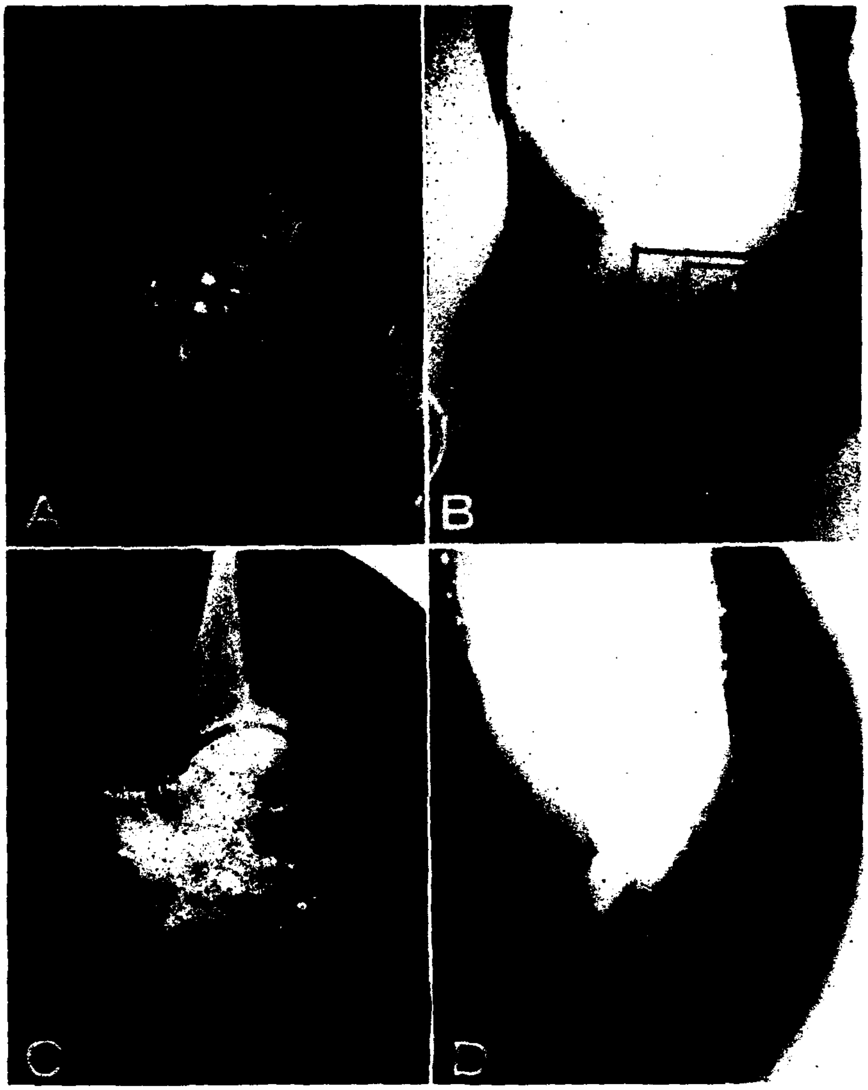

FIGURE 189.—Gunshot or shell fragment wound fracture of os calcis with sequestra and draining sinus, treated by excision of sinus, sequestrectomy, and obliteration of cavity within os calcis by osteotomy and internal fixation with stainless steel screw extending from lateral to medial wall. A. Lateral roentgenogram of left rear foot and ankle on 18 January 1945, showing shattered os calcis, many metallic foreign bodies, and some sequestra. At this time, there is a draining sinus. B. Roentgenogram on same date of os calcis, from above downward. The inked lines indicate the surgeon's proposed resection in the sagittal plane and the osteotomy of the lateral wall of the os calcis in the horizontal plane. C. Lateral roentgenogram of same rear foot on 25 April 1945, 3 months after operation. Screw is visible at forward part of os calcis. Wound is healed. D. Roentgenogram of os calcis from above downward, showing greatly narrowed os calcis with fractures healed and no sequestra seen. The screw through the anterior body of the os calcis is now barely discernible.

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CHAPTER XXVII

Military Shoes

Alfred R. Shands, Jr., M.D., and *Mather Cleveland, M.D.*

HISTORICAL NOTE

The first issue of footgear in World War I was the peacetime shoe recommended by the Munson Board in 1912 (*1–5*). A somewhat sturdier marching shoe was available in May 1917, but it was not until the spring of 1918 that a heavier shoe, of better waterproof construction, was developed to meet the necessities of trench warfare. This so-called Pershing boot, which was made of leather, with the flesh side out, and with a hobnailed sole, was generally considered to meet combat demands admirably. It was estimated to provide satisfactory fitting for 98 percent of all troops.

Shoes constructed on the same lines as the Pershing boot but with a more marked inflare were sometimes issued, but they were considered less suitable for combat purposes. The feet of younger men easily adjusted to their more pronounced curves, but the feet of older men did not, and calluses or corns developed on the toes where they pressed against the outer border of the shoe.

Shoes frequently were not fitted correctly in World War I for a number of reasons, including insufficiency of supply, irregularity in time of issue, lack of properly trained fitters, and the attitude of the soldiers themselves. Necessary alterations could be made in shoes issued within 3 days after induction, which was the regulation period of quarantine, if the supply was adequate. When, however, men were being called into service in large numbers, an insufficient supply was an immediate result. As for the soldiers' attitudes, many men with poorly developed feet, and some men not used to wearing shoes regularly, did not appreciate refinements of fitting and used every possible expedient to secure the sizes they had always worn.

Officers and enlisted men in charge of shoe fitting were given special instruction in this skill, as well as in the general care of the feet and the treatment of minor orthopedic affections. A sufficient number were thus trained to staff units going overseas. The need for men with this training, as well as the need for already trained chiropodists, became evident early in the war. The necessary authority was therefore secured, and through the cooperation of the officers of the National Association of Podiatrists,

The Surgeon General was notified whenever qualified chiropodists were inducted into the Army, so that orders could be written immediately for their assignment to the Sanitary Corps, to work under the orthopedic division.

Cobblers (shoemakers) also were extremely useful. When they were located among the troops, the most practical plan was to ask for their temporary assignment to an orthopedic department, train them in the making of orthopedic alterations in shoes, and, when they were competent to work under only nominal supervision, release them to return to their original units.

The only real contribution to the knowledge of shoe requirements made during World War I concerned methods of making alterations for the correction of postural and other requirements. Necessary materials for these purposes were furnished as part of cobblers' equipment.

As the war progressed, the good effect of wearing properly fitted army shoes was striking. Corns, calluses, bunions, crooked toes, ingrown toenails, and arch troubles, all seen in great numbers in the new recruits, tended to improve and even to disappear. Also, the normal use of the whole foot resulted in a marked development of all its tissues and gave it "an appearance of health commensurate with the work it had to do."

DEVELOPMENT OF THE WORLD WAR II ARMY SHOE

The Munson shoe used in World War I underwent some modifications after the war to make it suitable for a small peacetime Army with a high regard for appearance (*6*). This shoe was made with the grain side of the leather out, polished upper leather, full leather outsoles, and whole leather heels. Some official studies of combat type footgear were made in the 20 years after the war, but the specifications for service shoes were substantially unchanged until September 1941. Then, instead of profiting by the World War I experience, the Quartermaster Corps issued a peacetime shoe, exactly as had been done in World War I, and with the same unsatisfactory results, until finally a shoe of the Pershing type was again regulation, as many officers and enlisted men thought it should have been originally.

During the small scale maneuvers of the early prewar training period, the type I shoes first described were worn with reasonable satisfaction except for complaints that the outsole wore through within 2 or 3 weeks. Composition soles were substituted, and another shoe (type II) was developed with a rubber tap and heel (fig. 190). Then, just as the Army succeeded in producing a sole that would wear satisfactorily, a rubber shortage developed, and it became necessary to make the taps entirely of reclaimed rubber.

Various other changes also had to be made, to conserve leather, brass, and other components of the service shoe, with the unfortunate result that

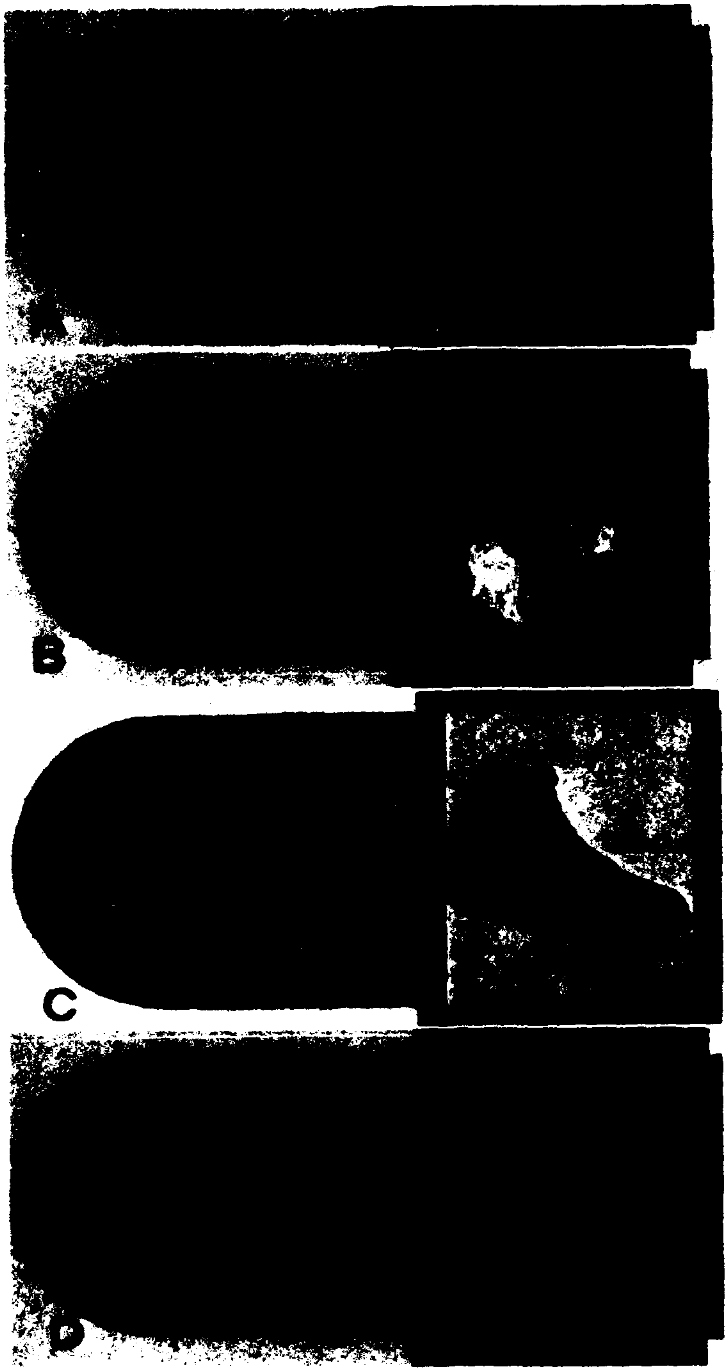


FIGURE 190.—Approved models of army shoes and socks. A. Low-quarter tan shoes with approved socks. B. Safety shoes, with composition soles and with approved sock combination. C. Service shoes, with composition soles (type II), with approved sock combination. D. Service shoes, with reversed upper and composition soles (type III), with approved sock combination. (War Department Technical Manual 10–228, 15 Feb. 1946.)

the issue shoe was being weakened just when the sturdiest possible combat footgear was becoming essential. When Gen. George C. Marshall, USA, returned from North Africa early in 1943, he reported that the new service shoes were entirely unfit for field use and that he intended to request the development of a shoe along the lines of the field shoe issued in France in World War I.

A new (type III) shoe was then developed, with flush-out upper leather and full sole and heel of rubber (fig. 190). Later, reclaimed rubber and, still later, synthetic rubber were substituted for the natural rubber used originally. At the same time, it was decided to introduce a new combat shoe for test purposes. This shoe was similar in many respects to the type III shoe, but it was 10 inches higher and had a cuff and buckle instead of lacers.

Delivery of the new model began in April 1943, and by July of this year, experimentation with it was fairly well advanced. All field tests were favorable, and in November 1943, the new shoe was standardized. Production began in January 1944. The shoe was generally well received, except for complaints from the European theater that it offered only relatively minor protection against mud, slush, and cold and was, therefore, contributory to trench foot. The role of footgear in the etiology of trench foot is discussed in the volume on cold injury in this historical series (*7*).

In January 1944, the War Department announced that soldiers in combat areas, who had previously required five pairs of shoes annually, were then receiving only 3½ pairs over the same period (*8*). Men in the Zone of Interior were receiving slightly less than two pairs per year. The decreases in issue were credited to improvement in the design of the shoe and in manufacturing methods.

SHOE FITTING

Army regulations dealing with measuring of feet and fitting of shoes were first issued in World War II on 6 July 1942 (figs. 191 and 192) (*9*). Changes were issued on 15 April 1943 (*10*), and regulations dealing with the fitting of socks as well as shoes were issued on 9 June 1943 (*11*). The regulations issued on 29 March 1945 dealt with the general subject of fitting U.S. Army military footwear.

The Army regulations issued on 9 June 1943 were a considerable expansion of early regulations and were definitive. They were summarized in the November 1943 issue of *The Bulletin of the U.S. Army Medical Department* as follows (*12*):

1. Company commanders are responsible for proper measurement and fitting of shoes for their men.

2. The Quartermaster is responsible for the provision of a fitting room and of measuring machines and equipment. He is also responsible for the assignment of experienced personnel to the clothing issue warehouse.

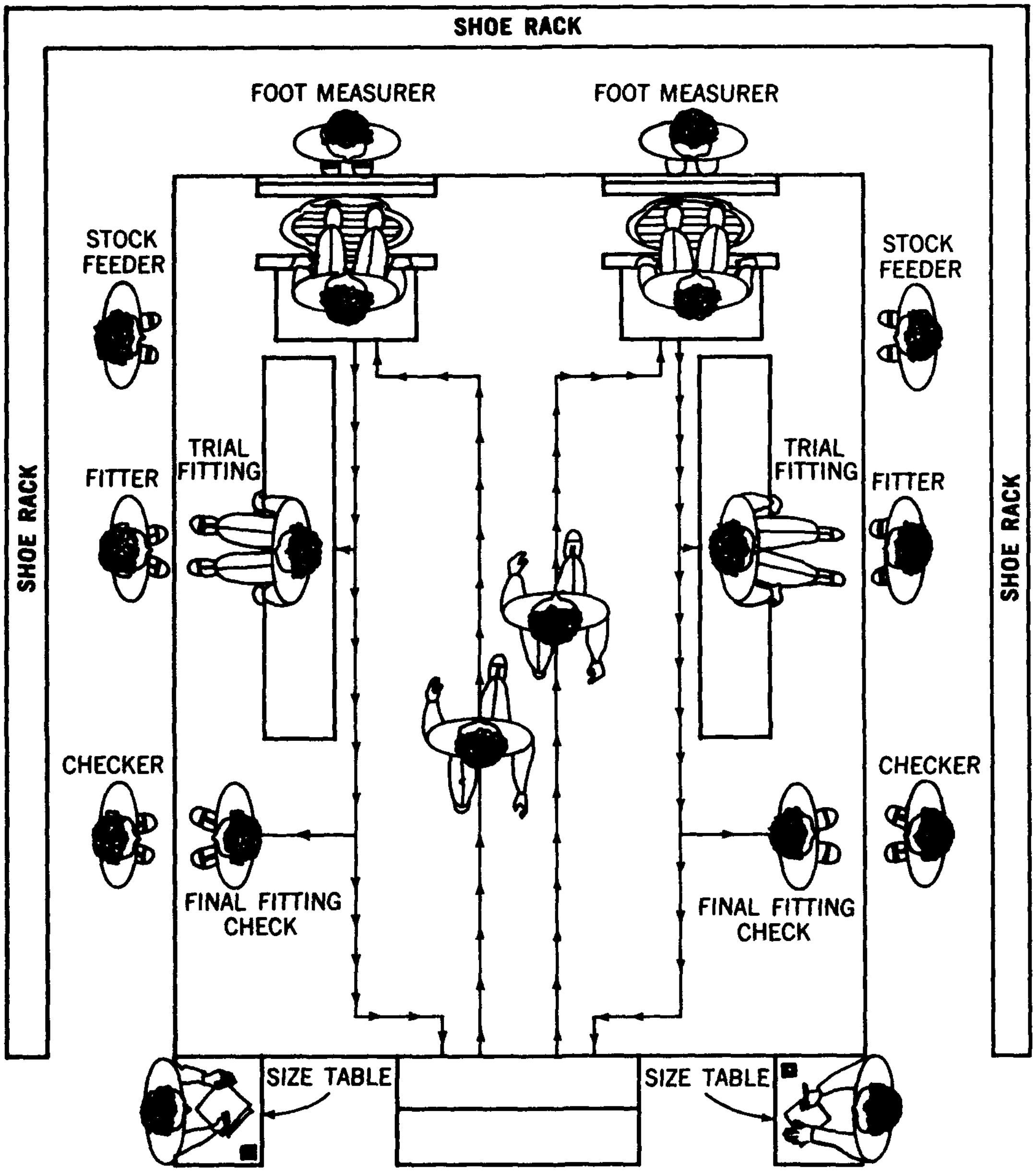


FIGURE 191.—Foot measuring and shoe-fitting platform, approximately 12 feet 9 inches long, 10 feet wide, and 2½ feet high, large enough for two complete crews of measurers and fitters to operate at the same time. A complete stock of service shoes in all authorized tariff and nontariff sizes is arranged by size in racks extending around the sides and rear of the platform. (Army Regulations No. 850–125, 6 July 1942.)

3. The proper size of the shoe is determined by measurement of the foot on the foot measuring machine and by trial fitting.

4. The size determined is recorded on the individual's service record and on his clothing and equipment record. Later changes in size are similarly recorded.

5. If an exchange of shoes proves necessary, a qualified commissioned officer must check the fit of the shoes presently provided and make arrangements for their replace-

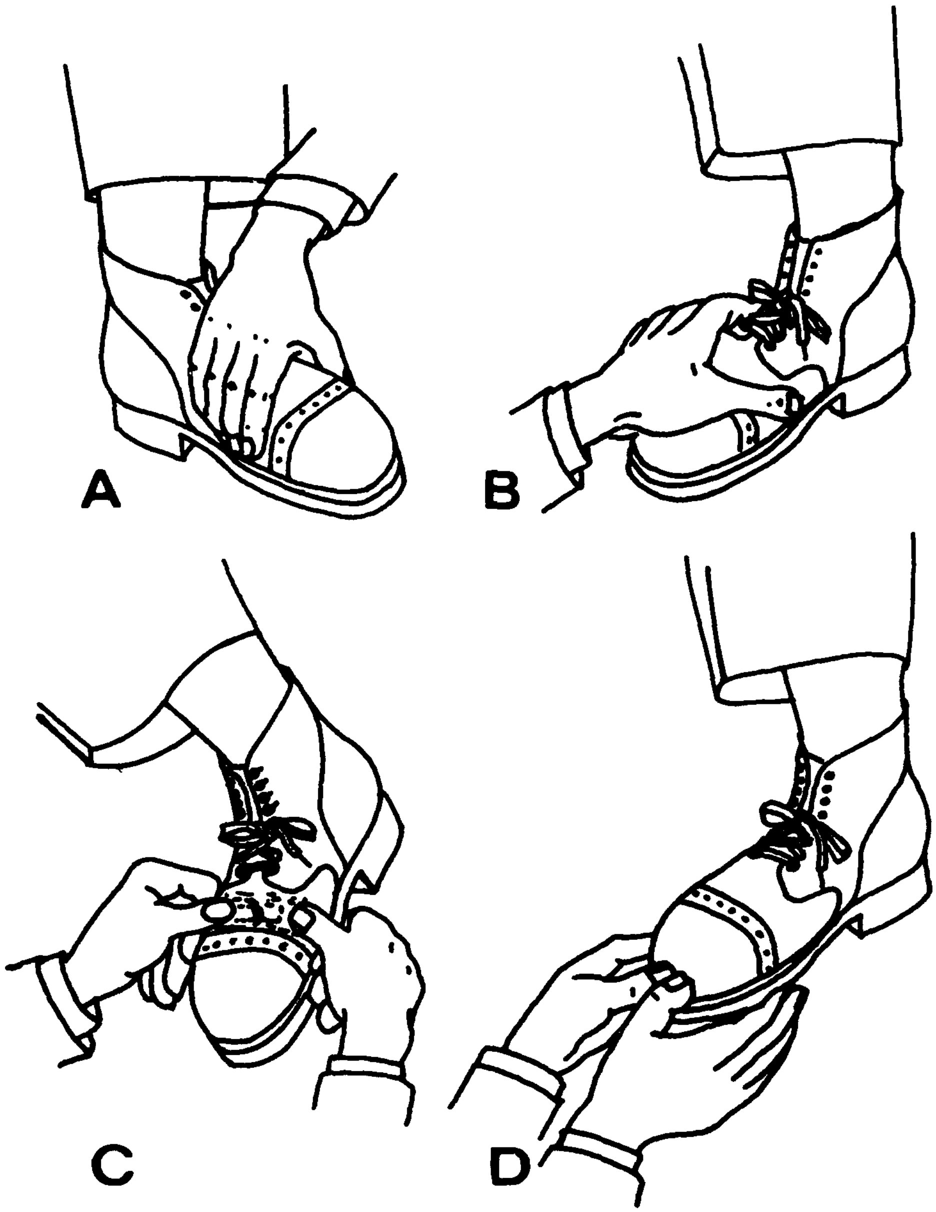


FIGURE 192.—Final fitting tests of shoes: A. Test for snug fit under arch. B. Test for proper position of ball joint. C. Test for sufficient width across ball of shoe. D. Test for sufficient length. (Army Regulations No. 850–125, 6 July 1942.)

ment under existing regulations. He must not specify the size of issue, which can be determined only by second measurements and trial fitting.

When these directions were prepared, it was expected that orthopedic clinics would be provided with foot measuring machines (Brannock or Clarke) of the type used in local warehouses, so that soldiers with foot complaints could be checked for possible misfitting. Even if errors were

found, recommendations for change of shoes would be advisory only. Any action would depend on an actual trial fitting.

Army Regulations No. 850–125, issued on 29 March 1946 (*13*), dealt chiefly with the administrative aspects of fitting military footgear and referred to War Department Technical Manual 10–228, February 1946 (*14*), for directions for taking the measurements and fitting the shoes (fig. 193).

Proper care of shoes and socks played a role in the reduction of foot disabilities. It was directed that new shoes be rubbed daily with saddle soap until the leather became pliable, after which they should be polished regularly. They should be kept dry. Whenever possible, different shoes should be worn on different days.

Trainees were advised to wear wool socks on duty, and to change them once or twice daily. Some orthopedic surgeons recommended that two pairs of wool socks be worn on long marches, but others considered this a bad plan on the ground that the shoes had not been fitted for the containment of an extra pair of socks.

LASTS

A comprehensive study of lasts of army shoes was made by Maj. Thomas Beath, RCAMC, and issued, after revision, on 23 September 1945 (*15*). It was based on observations made in Montreal, Canada, and in Boston, Mass., and was stimulated by the studies made at Fort Knox, Ky., and to be reported later in this chapter (p. 803). It was also aided by information secured from representatives of the Woodward and Wright Last Co. on lasts in general and from representatives of the United Shoe Machinery Corp., Boston, on special lasts.

The report contained a great deal of information on the making of lasts; on the lathes used in their manufacture, which is a highly specialized craft in itself; and on the military implications of the present status of the industry. Perhaps the most important consideration in the report, "which should be emphasized with great force," was that the needs of an army must be anticipated by 2 years or more before delivery of boots is required. Even with this allowance, considerable confusion might well occur when the demand for shoes in quantity arose.[1]

Major Beath rated the Canadian boot currently in use as good, though probably not so good as it should be; shoe manufacturers had purchased the lasts for it. In the United States, the Munson lasts, which were the property of the Army, had proved themselves capable of fitting more men than any other. An opposite opinion from a "few well informed persons" was that these lasts were faulty and that the shoes made from them had been "misfitted to more men" than those made from any other last in the world.

[1] A very serious shortage of army shoes might have developed in the United States, Major Beath noted, except for the action of manufacturers of lasts, who made their own calculations before the war and guaranteed to take delivery of all blocks of lasts the industry could produce under pressure, even though the estimates of the manufacturers were four times greater than those of the Quartermaster Corps. When the wartime need arose, the industry was, therefore, ready for it.

TM 10-228

T. O. 13-1-47

WAR DEPARTMENT TECHNICAL MANUAL

FITTING OF SHOES AND SOCKS

WAR DEPARTMENT • FEBRUARY 1946

Contents

FIGURE 193.—War Department Manual or fitting of shoes and socks. (Top) Cover. (Bottom) Table of contents. (War Department Technical Manual 10–228, 15 Feb. 1946.)

Major Beath's personal comments on the Munson last were as follows:

1. The last is wide in the anterolateral toe region.

2. The medial margin of the forepart extends straight forward from the ball of the great toe instead of deviating somewhat laterally.

3. The vertical height in the region of the head of the fifth metatarsal is much less than usual.

4. The length of the rear half seems somewhat too great, and the excess affects the position of the heads of the first and fifth metatarsals, which are placed too far back. In particular, the head of the fifth metatarsal seems to lie in the narrowing region approaching the shank of the shoe and is, therefore, liable to compression for two reasons, (a) that this region of the last and the shoe has not enough vertical height and (b) that the head of the fifth metatarsal lies back of the region of maximum breadth of the shoe.

Army shoes, Major Beath concluded, should be based on the best possible research, and there should be no delay in initiating the fabrication of new lasts based on such studies. The making of new lasts implied the making of new lathes and, as a corollary, the construction of better devices for measuring the feet than those currently in use (Kerby, Scholl, Brannock, and Clarke).

In a report issued on 12 June 1945 from the Army Medical Research Laboratory at Fort Knox, Capt. Arthur Freedman, MC, and T4c. Charles M. Kirkpatrick (*16*) pointed out that it was a mistake to assume that changing the last currently in use for U.S. Army shoes would correct the errors in shoe fitting. It would not. These errors derived only in part from faulty design. Faulty issue was equally prominent, and if existing errors of fitting continued, no modification of the last would produce any improvement at all. Major Beath's conclusions were substantially the same.[2]

PROVISION OF CORRECTIVE AND OTHER SPECIAL SHOES

Development of Foot Imprints

The provision of special shoes for men with special foot problems was a major consideration in the U.S. Army of many millions of men in

[2] Up to 1886, Major Beath pointed out, in a review of the history of the development of lasts, no concerted action seems to have been taken by shoe manufacturers, last designers, pattern designers, or retailers toward obtaining a common basis upon which all shoes should be made. Every individual carried out his own ideas in regard to sizes and their computation, although some manufacturers took the initiative of prescribing measurements by which their shoes should be made. The chaotic situation introduced many selling problems, in which the retailer suffered most.

At the 1886 annual convention of the Retail Shoe Dealers' National Association of the United States, in Philadelphia, Pa., it was decided, by unanimous vote of the members present, that adoption of standards for the measurement of lasts would be of benefit to the trade. The pooling of facts and figures gleaned from the total trade resulted in fixed sets of measurements for men's, women's, misses', boys', youths', and children's shoes. The data were reported in February 1887, and for the next 38 years, there were only slight deviations from the original code.

In 1924, the Dayton Last Works, Dayton, Ohio, published a booklet (*18*) (no longer available), which contained the dimensions of average lasts for men, women, and children, and gave the gradients (that is, the amount that an actual measurement changes for changes in size and width). The principal gradients remained unchanged in the following years and were the criteria used for the U.S. Army Munson last. The booklet just mentioned represented the nearest approach that could be obtained to measurements used by the majority of manufacturers of lasts and shoes.

World War II (*17*). The problem fell into two distinct periods. During the first, the problem chiefly concerned men with disabilities and deformities preexistent to their induction. During the second, it continued to concern these men but now chiefly concerned men who had sustained combat-incurred injuries.

Procurement of Special Shoes

Early in the war, any soldier with special foot problems who could not be fitted properly from one of the 220 sizes provided in the regulation service shoe received certification to this effect by the appropriate medical officer. Before the establishment of a special program for the provision of accurately fitted, comfortable shoes for battle casualties, requests for such shoes were handled by the Special Measurement Shoe Section of the Boston Quartermaster Depot. A very high proportion of satisfactory fits was obtained by the techniques employed, but the approach was subject to many inaccuracies, beginning with the initial measurement of the foot. The experience of the personnel who did the measuring and fitting also played a large part; measurement of a yielding foot was difficult, and when the measurements were taken by individuals unfamiliar with last specifications, errors that were apparently minor could result in important differences in size.

When special shoes were requested through channels for feet that were deformed congenitally or as the result of disease or trauma, the necessary papers (fig. 194) were usually accompanied by a plaster cast of the foot to be fitted, which was almost always an inaccurate duplicate. This statement is warranted by examination of large numbers of casts sent to the Boston Quartermaster Depot and from examination of correspondence in the files of the Special Measurement Shoe Section. Information concerning how the cast was made (in the weight-bearing or non-weight-bearing position) seldom accompanied the requisition, and time-consuming and unsatisfactory correspondence was necessary to secure it.

Clearly, the first necessity in the provision of correctly fitted special shoes was to develop a workable foot imprint which would approximate that taken in dry sand.

Some 25 years before World War II, Gaynor O'Gorman, Director of the Research Division of the United Shoe Machinery Corp., began work on this project, which was finally accomplished by construction of a machine whose basic principle was the use of a box of ⅙-inch steel ballbearings and two electromagnets (fig. 195). When the electromagnets, which were attached to the under side of the box, were activated as the patient stood in the box, the bearings were frozen into a solid mass and an imprint was created from which, by a series of moulding operations, a positive imprint of the weight-bearing foot was obtained. By this technique, the alteration which occurred when the impression was made with the patient standing on a hard, flat surface was entirely avoided. The research just described was done chiefly on feet deformed by

WD AGO Form 10-101
1 November 1944
This form supersedes WD AGO Form 10-101, 25 August 1944 (Old QMC Form 407, 8 January 1941) which may be used until existing stocks are exhausted.

SPECIAL MEASUREMENT BLANK

UNITED STATES ARMY LEATHER BOOTS AND SHOES

GENERAL INSTRUCTIONS

1. THIS SPECIAL MEASUREMENT BLANK WILL BE USED ONLY IF THE ENLISTED PERSON CANNOT BE PROPERLY FITTED WITH U. S. ARMY BOOTS OR SHOES WITHIN THE REGULAR OR SUPPLEMENTAL TARIFF SIZE RANGES. THIS BLANK IS NOT TO BE USED IF A SUPPLEMENTAL TARIFF SIZE OF BOOT OR SHOE IS REQUISITIONED. IT MAY BE USED BOTH FOR ENLISTED MEN AND ENLISTED WOMEN.

2. ALL MEASUREMENTS SHOULD BE TAKEN CAREFULLY TO MAKE CERTAIN THAT THE SPECIAL MEASUREMENT BOOTS AND SHOES WILL FIT PROPERLY. STUDY ALL DIAGRAMS AND INSTRUCTIONS CAREFULLY AND DO NOT DEVIATE FROM THEIR DIRECTIONS.

3. THE NAME, GRADE, SERIAL NUMBER AND ORGANIZATION OF THE ENLISTED PERSON FOR WHOM SPECIAL MEASUREMENT BOOTS OR SHOES ARE REQUISITIONED SHOULD APPEAR ON ALL REQUISITIONS FOR SPECIAL MEASUREMENT BOOTS OR SHOES. DO NOT SPECIFY A DEFINITE SIZE AND WIDTH OF BOOT OR SHOE ON A REQUISITION FOR SPECIAL MEASUREMENT BOOTS OR SHOES.

4. A SPECIAL MEASUREMENT BLANK NEED NOT ACCOMPANY A REPLENISHMENT REQUISITION FOR THE SUPPLY OF ADDITIONAL PAIRS OF SPECIAL MEASUREMENT BOOTS OR SHOES, UNLESS THE SPECIAL MEASUREMENT BOOTS OR SHOES WHICH WERE PREVIOUSLY SUPPLIED DO NOT FIT SATISFACTORILY.

5. IF A CAST OF EITHER OR BOTH FEET IS REQUIRED, IT SHOULD BE MADE WHILE THE SUBJECT IS STANDING IN BARE FEET AND SHOULD INCLUDE THE LEG TO A DISTANCE OF AT LEAST TWO INCHES ABOVE THE ANKLE BONE. THE CAST SHOULD BE PLAINLY MARKED WITH THE NAME AND SERIAL NUMBER OF THE ENLISTED PERSON AND FORWARDED TO THE BOSTON QUARTERMASTER DEPOT.

6. ONLY ONE COPY OF THIS SPECIAL MEASUREMENT BLANK IS REQUIRED. SEND THE COMPLETED SPECIAL MEASUREMENT BLANK AND REQUISITION DIRECT TO THE BOSTON QUARTERMASTER DEPOT.

NAME	SERIAL NUMBER	GRADE	DATE
ORGANIZATION	POST OR STATION		

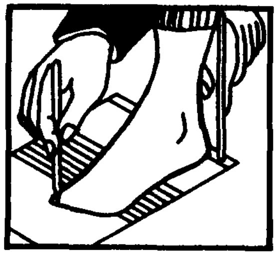
HEIGHT	WEIGHT	REQUISITION NUMBER

CERTIFICATE OF MEDICAL OFFICER

I CERTIFY THAT THIS INDIVIDUAL CANNOT BE PROPERLY FITTED WITH U. S. ARMY BOOTS OR SHOES WITHIN THE REGULAR OR SUPPLEMENTAL TARIFF SIZE RANGES AND THE SUPPLY BY SPECIAL MEASUREMENT AS INDICATED HEREIN IS REQUIRED.	SIGNATURE OF MEDICAL OFFICER

REMARKS

FIGURE 194.—Special form for procurement of corrective shoes.



1. REMOVE THE SHOES, DO NOT REMOVE THE SOCKS OR STOCKINGS. PLACE THE REAR END OF THE HEELS AT THE POINTS BELOW INDICATED BY THE ARROWS SO THAT THE FEET LIE IN A STRAIGHT LINE. DRAW A COMPLETE OUTLINE OF BOTH FEET WHILE THE ENLISTED PERSON IS STANDING *WITH THE WEIGHT EVENLY DISTRIBUTED ON BOTH FEET. HOLD THE PENCIL STRAIGHT UP AND DOWN THROUGHOUT THE TRACING OPERATION* AS INDICATED IN THE "FOOT TRACING" DRAWING AT THE LEFT.

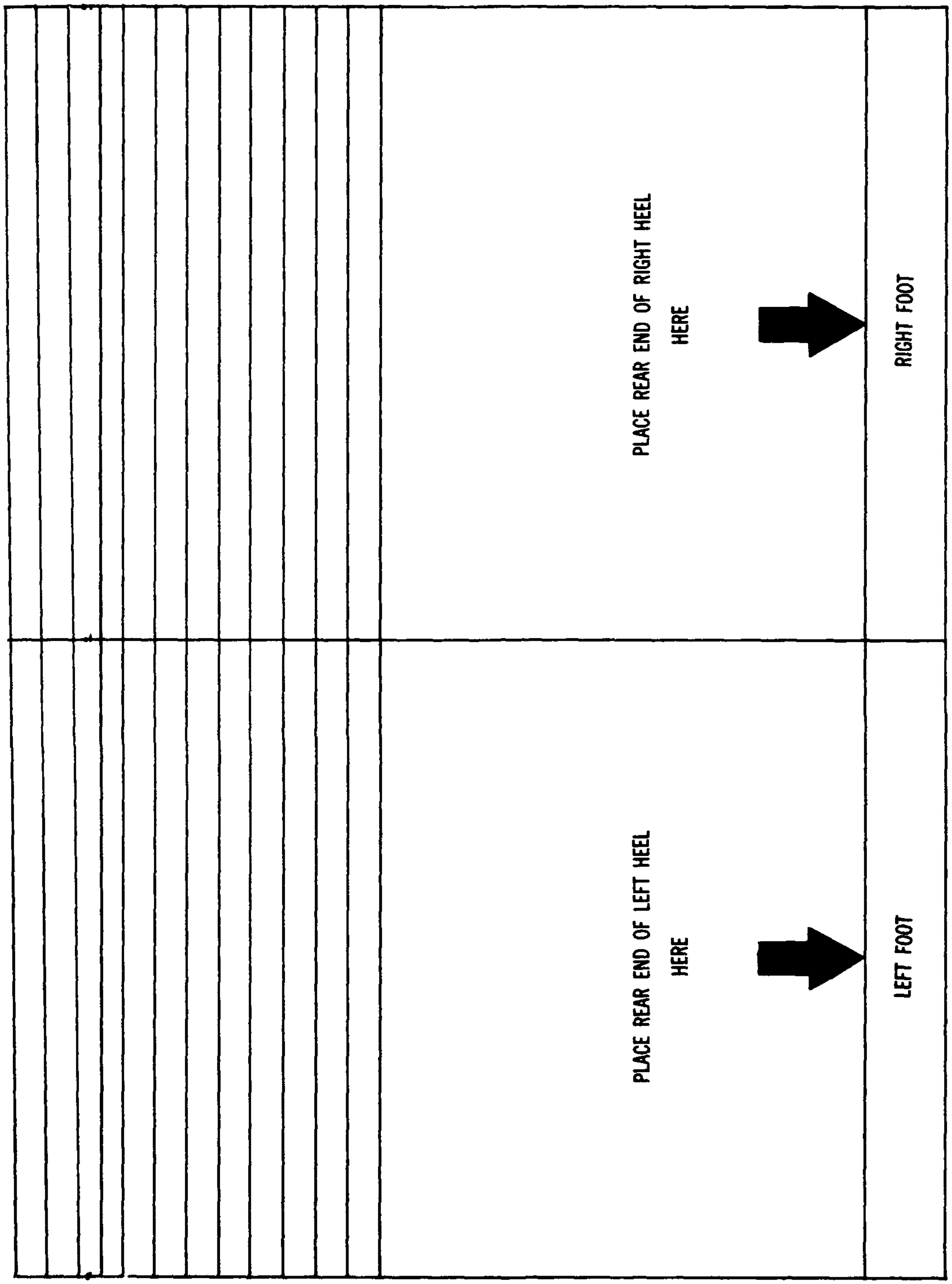
2. BRIEFLY AND ACCURATELY DESCRIBE BELOW OR ON AN INCLOSED SHEET THE TYPE, MEASUREMENT, AND LOCATION OF THE FOLLOWING UNUSUAL FOOT CONDITIONS OF THE ENLISTED PERSON, ALWAYS DESCRIBING THE RIGHT AND LEFT FOOT INDIVIDUALLY: CALLUSES ON THE BOTTOM OF THE FOOT, CLUB FOOT, CLAW FOOT, HAMMER TOE, ENLARGED INSIDE BALL POINT, AND ANY SEVERE INJURY TO THE WAIST, INSTEP, OR ANY OTHER PORTION OF THE FOOT.

3. COOKIE INNERSOLES, HEEL WEDGES, OUTERSOLE WEDGES, HEEL LIFTS, ORTHOPEDIC HEELS, AND ANY OTHER NECESSARY ORTHOPEDIC ADJUSTMENTS WHICH SHOULD BE INCORPORATED IN THE FINISHED BOOTS OR SHOES WILL BE ACCURATELY DESCRIBED BELOW OR ON AN INCLOSED SHEET AS TO TYPE, MEASUREMENT, LOCATION, OR ANY OTHER PERTINENT DETAIL; ALWAYS STATE WHETHER SUCH ADJUSTMENTS APPLY TO THE LEFT, THE RIGHT, OR BOTH BOOTS OR SHOES.

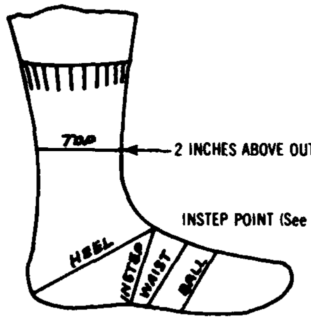
4. THE SHOE SIZE AND WIDTH REGISTERED BY THE CURRENT STANDARD U. S. ARMY MEN'S OR WOMEN'S FOOT MEASURING OUTFIT ARE AS FOLLOWS:

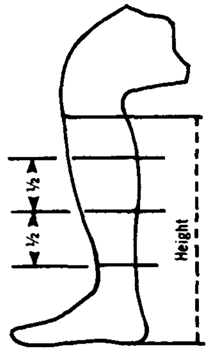
RIGHT SIZE ______ RIGHT WIDTH ______ LEFT SIZE ______ LEFT WIDTH ______

FIGURE 194.—


PLACE REAR END OF RIGHT HEEL
HERE
RIGHT FOOT
PLACE REAR END OF LEFT HEEL
HERE
LEFT FOOT

Continued.





FOOT MEASUREMENTS	RIGHT-INCHES	LEFT-INCHES	LEG MEASUREMENTS	RIGHT-INCHES	LEFT-INCHES
BALL (WIDEST PART)			HEIGHT		
WAIST			TOP		
INSTEP			CALF		
HEEL			BELOW CALF		
TOP			ANKLE		

1. ALL FOOT MEASUREMENTS INDICATED ABOVE WILL BE SHOWN WHEN EITHER BOOTS OR SHOES ARE REQUISITIONED. ALL LEG MEASUREMENTS INDICATED ABOVE WILL BE SHOWN WHEN BOOTS ARE REQUISITIONED. WHEN SHOES ARE REQUISITIONED, THE LEG HEIGHT MEASURMENT WILL BE SHOWN UNDER THE "LEG MEASUREMENTS" DRAWING ONLY IF ONE LEG IS SUBSTANTIALLY SHORTER THAN THE OTHER.

2. USE AN ACCURATE FABRIC TAPE MEASURE IN THE TAKING OF THE FOOT AND LEG MEASUREMENTS. PLACE THE TAPE AROUND THE FOOT OR LEG AS INDICATED IN THE TWO DRAWINGS ABOVE AND PULL THE TAPE SNUGLY BUT NOT TIGHTLY. ALL MEASUREMENTS WILL BE TAKEN WHILE THE ENLISTED PERSON IS STANDING AND WEARING SUCH SOCKS OR STOCKINGS AS ARE STANDARD EQUIPMENT; WITH THE BOOTS OR SHOES WHICH ARE REQUISITIONED. BOTH THE RIGHT AND LEFT FOOT AND LEG MEASUREMENTS WILL BE RECORDED AS INDICATED UNDER THE TWO DRAWINGS ABOVE.

3. BEFORE TAKING THE HEEL MEASUREMENT SHOWN IN THE "FOOT MEASUREMENTS" DRAWING ABOVE, DETERMINE THE INSTEP POINT INDICATED IN THE "FOOT MEASUREMENTS" DRAWING ABOVE. THE INSTEP POINT OF MOST FEET IS THE APEX OF THE GIRTH MEASUREMENT OF THAT PORTION OF THE INSTEP WHICH MEASURES ½" GREATER THAN THE BALL MEASUREMENT. THE GIRTH MEASUREMENT OF A HIGH OR LOW INSTEP WILL DEVIATE FROM THIS STANDARD.

REMARKS

FIGURE 194.—Continued.

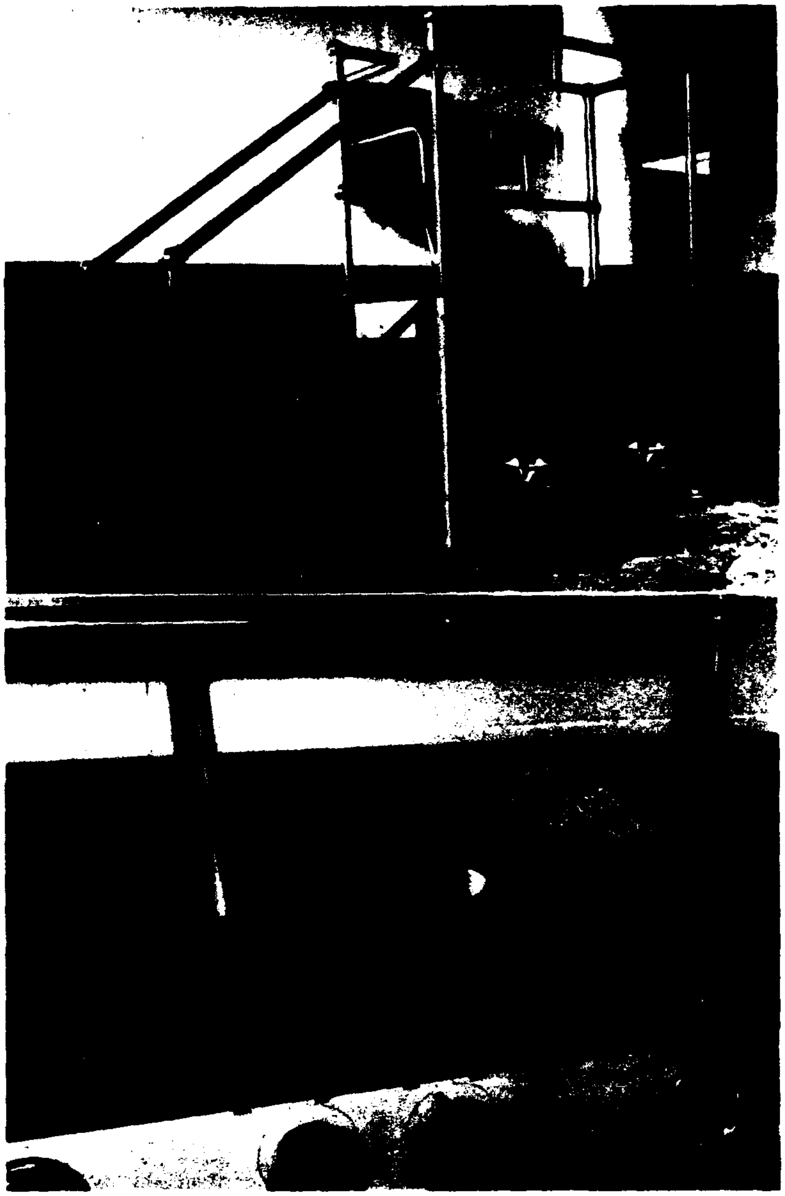


FIGURE 195.—Equipment for making molds for precise shoe fitting. (Top) Fitting machine equipped with box of $\frac{1}{16}$-inch steel ballbearings, under which is powerful electromagnet. (Bottom) Box of ballbearings. (Steinbergh, S. S.: Army-Navy Register, 21 July 1945.)

infantile paralysis, osteomyelitis, congenital deformities, and accidental injuries, but the system was readily applied to Army needs (*17*). A special technique based on this principle produced absolutely accurate casts of the affected feet (fig. 196). Until this method was fully developed, an interim procedure was used.

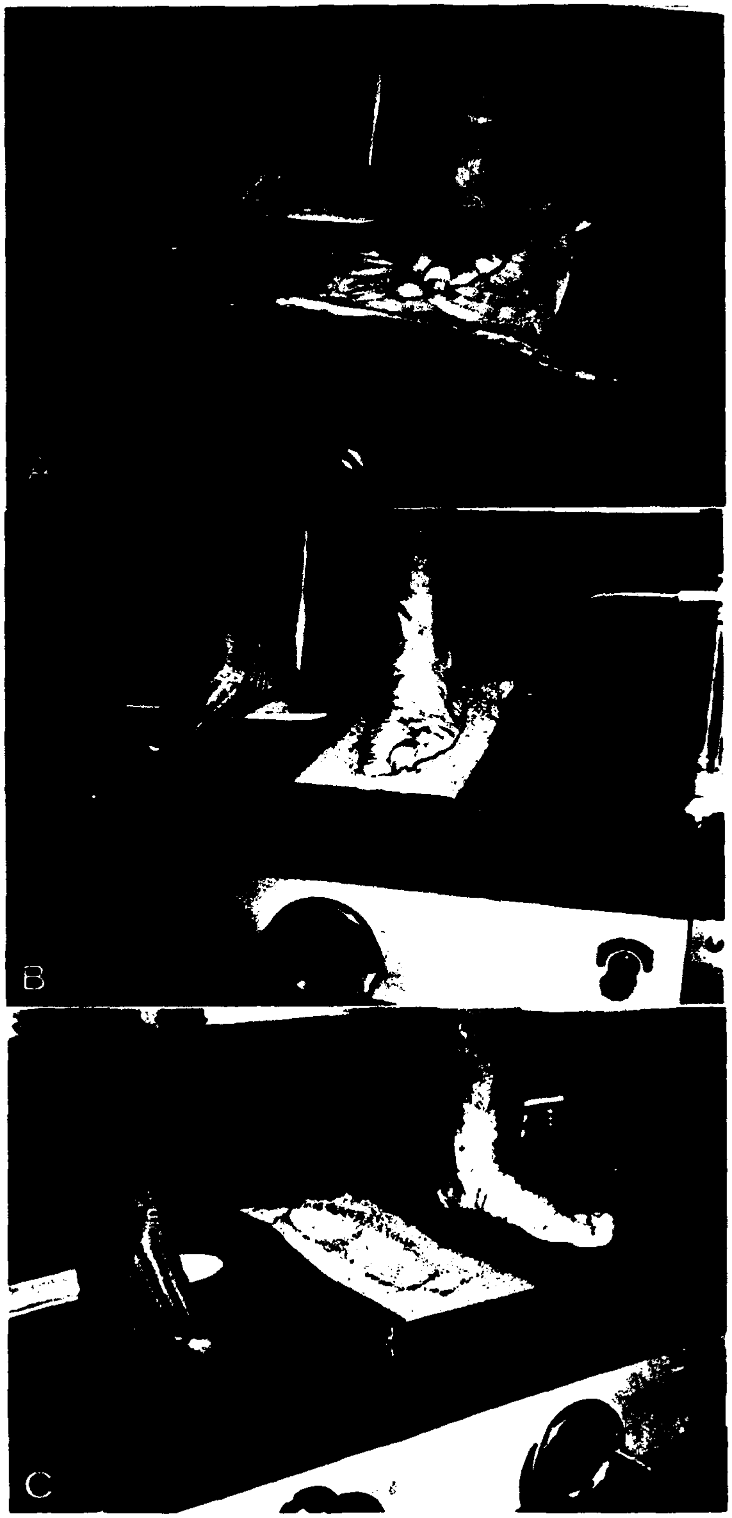


FIGURE 196.—*See opposite page for legend.*

FIGURE 196.—Steps in construction of mold. A. Imprint obtained by pressing foot into box of bearings, which are frozen in position by electromagnet. Rear of box can be adjusted for desired heel height. B. Imprint of foot, which is checked with pendulum-type gage at inside ball and outside ball of foot, and at heel. Adjustments can be made as necessary. C. Alterations before final imprint is secured. If leg shortening exists, the whole box is jacked up to the proper height. The rheostat is turned down to create a final arrangement of the bearings in the correct imprint. In the preparation of a plaster cast of the foot, a piece of rayon or silk stocking fabric impregnated with wax is tempered in fairly hot water and laid over the imprint and the entire box to prevent liquid plaster from running into the bearings. The foot is then replaced in the imprint, with the weight evenly borne. D. Plaster of paris poured into housing about foot and ankle with fins placed at junction of forefoot and hindfoot. After the plaster has set, the fins are jiggled and a dividing line is created between the fore and rear parts of the mold, so that the foot can be removed. E. Mold reassembled after interior has been painted with a soap or oil separating solution. It is then filled with a solution of plaster of paris to obtain an accurate cast of the foot.

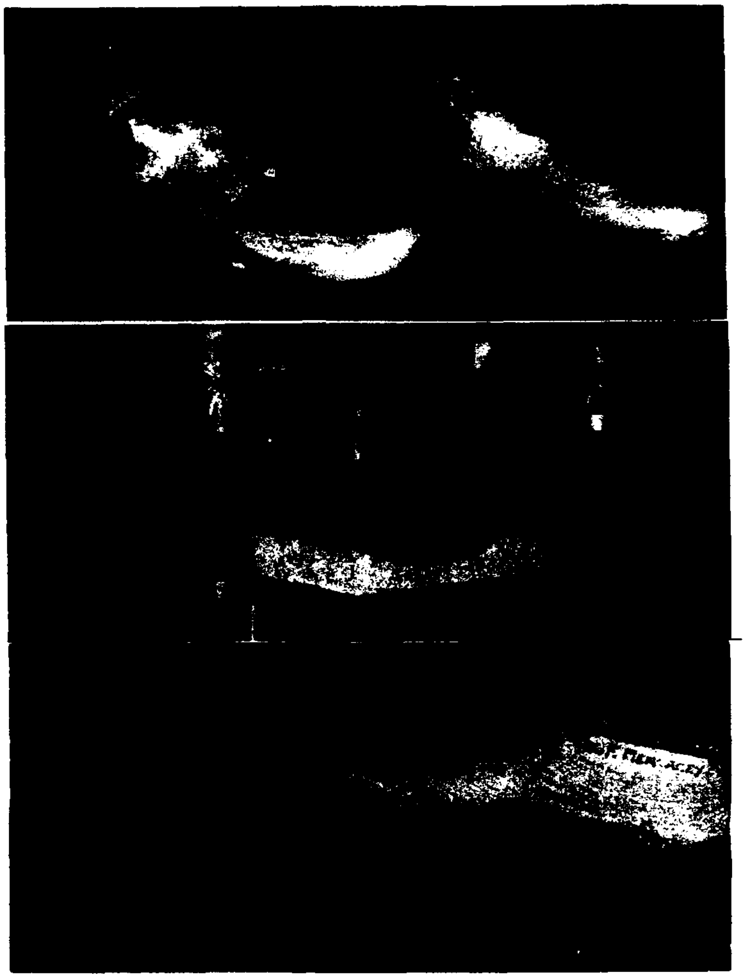


FIGURE 196.—Continued. F. Metal model constructed from plaster cast and duplicated in wood on duplicating table. G. Cork inner mold pressed from woodlast and affixed to it. H. Cast and inner mold ready to be sent to shoe factory. (Space does not permit inclusion of all the details of this technique of shoe fitting. Interested readers are referred to the original report (Steinbergh, S. S.: Army-Navy Register, 21 July 1945), which is on file in the Historical Unit, AMEDD, Office of The Surgeon General, Department of the Army.)

Establishment of an Orthopedic Shoe Clinic

The establishment and operation of an orthopedic shoe clinic, as a joint project of the Surgeon General's Office and the Quartermaster Corps, was begun at the Boston Quartermaster Depot on 2 July 1945 (*17*). Maj. Saul S. Steinbergh, MC, was assigned to the depot during the evolution of the project and the subsequent period of instruction.

In November 1944, only Walter Reed General Hospital, Washington, D.C., in addition to the Boston depot, possessed the units just described. Later, they were provided at seven other general hospitals and at two

station hospitals at training camps. The facilities of the Boston depot were made available to the Veterans' Administration.

Courses of instruction were set up at the Boston depot for the enlisted technicians (SSN 366) who would operate the units under the supervision of orthopedic surgeons. Each class was composed of 10 technicians, and instruction for each group lasted 8 weeks. It included elementary regional anatomy, physiology, and pathology as well as technical training.

After the machines were installed in the selected hospitals and the technicians trained to operate them, all patients in need of special shoes were sent to the most convenient of these hospitals for measurements of their feet with the electromagnetic units and were then returned to their own hospitals. When the new method became operative, it was estimated that about a thousand such patients were then in regional and general hospitals in the Zone of Interior.

After the casts were made, they were sent to the Boston Quartermaster Depot Clinic, where the job sheets were reviewed and any corrections necessary were made. After the shoes were made, they were inspected at the depot before they were sent to the hospitals in which the impressions had been made. This step was essential because minor final adjustments were frequently required. Even patients who had been weight-bearing for several weeks when the impressions were made and who then had no demonstrable pitting edema often presented themselves with the girth of their shoes reduced by one or two sizes during the 4 to 6 weeks the shoes had been under construction. To obtain a proper fit, it was then necessary to add a light cork inner sole beneath the inner mold and to place the same amount of cork or leather beneath the heel seat of the opposite foot to maintain equal length of the extremities. When it was believed that all changes in the foot had occurred, the best plan of all was to make a new impression and a new last. If this was not practical, the last was shaved to compensate for the shrinkage, or, if the shrinkage was only one size, a new wood was turned out on the duplicating lathe.

Since these procedures all took time (as well as effort and money), a convalescent shoe was developed to be worn in the period of shrinkage (fig. 197). One model of this surgical shoe laced completely down the front, from the end of the toes, and the other laced down the back of the heel also. These shoes, which were cosmetically appealing, had highly adjustable quarters and wide gussets. Originally, adjustments were made by elastic bandages and packing. The shoes were worn until these adjustments were no longer needed and it was certain that all edema had disappeared. Then, if a standard shoe could not be worn, measurements were taken and whatever special shoe was necessary was prescribed.

The special shoes needed for amputees are discussed under that heading (p. 967). Special shoes were also needed for men with deformities of the feet resulting from severe fractures, painful scars, and other residua

FIGURE 197.—Hospital shoe (left), with soft uppered high top, built on last of army oxford. Convalescent shoe (right) made of light soft kid, with wide tongue and front and back lacings.

of combat-incurred wounds. In many such cases, properly fitted special shoes permitted them to bear weight and to walk with little or no discomfort. The largest group of patients observed at the Boston Quartermaster Depot Clinic were casualties from antipersonnel mines, whose injuries were chiefly comminuted fractures of the calcaneus and other bones of the hind foot articulating with the calcaneus. In such cases, there was widening or loss of parts of the calcaneus, usually with marked restriction of inversion or eversion; loss of total extremity length, averaging from one-half to three-fourths of an inch; and loss of arch height because of loss of calcaneal height. The correction of such defects was far more complicated than might seem at first glance; building up the heel, for instance, did not in itself compensate for shortening of the length of the extremity. Each injured foot presented an individual problem which had to be solved individually.

MINOR ALTERATIONS OF THE MILITARY SHOE

In addition to the provision of arch supports, minor shoe adjustments for minor ailments consisted of the application of anterior heels, orthopedic heels, wedges, and other supports. In War Department Circular No. 152 of 3 July 1943 (*19*), it was specified that these adjustments, as well as the provision of arch supports, could be made only on prescription by an orthopedic surgeon or other qualified medical officer; the prescription was to become part of the man's service record and was to accompany the shoes presented for adjustment, wherever the work was to be done. On 21 July 1943, the original provision for duplicate prescriptions was

changed to a requirement for quadruplicate prescriptions (*20*). In the earlier of these circulars, it was specified that the prescription must be accompanied by a diagram showing complete dimensions and a detailed description of the required alterations. Provision was also made for the duplication of previous adjustments.

The minor repairs just described were made in quartermaster shops when such shops were available. When they were not, the work was done in civilian repair shops approved by the commanding officer of the post, camp, or other station. The Quartermaster Corps provided excellent cooperation in all work of this sort.

ARCH SUPPORTS

During World War II, a number of different types of arch supports were used, with varying degrees of success or, more often and more correctly, lack of success. The objective that had been set was practically impossible to achieve: As has been pointed out elsewhere, arch supports never made a combat soldier.

Circular Letter No. 154, of the Surgeon General's Office, dated 30 August 1943, contained instructions for the issuance of insert type arch supports as follows (*21*):

1. Although efforts were made to exclude men with weak arches from the Army, experience showed that weakness developed in a substantial number after induction and greatly impaired their usefulness. Previous programs of correction had been inadequate, and the following program was outlined for the future:

2. Three types of insert arch supports were approved for issuance to authorized personnel and no other styles would be provided:

a. Plantar (longitudinal).

b. Metatarsal (transverse).

c. Combination (longitudinal and transverse).

This policy would permit the maximum number of corrections with the minimum number of sizes. The approved styles would be furnished only in full sizes for men, from 6 to 12, and in D width. For women, transverse and combination styles would be provided, from 3 to 9, in B width. In the limited number of cases in which these styles and sizes were not adequate, provisions of previously approved programs could be invoked. Minor fitting adjustments could be made on the insert supports with a sharp knife.

3. The entire arch support program was to be under the direct supervision of the orthopedic section in each hospital.

4. Supports would be issued only on the prescription of medical officers. Clinical records were to be maintained, and proper entries were to be made on individual service records.

5. Supports were to be made of soft, resilient leather, with reclaimed rubber arch cushions, and were to be assembled, sewed, and cemented as approved in commercial manufacture.

6. All deliveries of arch supports for the remainder of 1943 were to be for overseas hospitals. The first distribution in the Zone of Interior would be on 1 January 1944. The initial issue would be one pair per person. Arch-O-Graph supports could be used

alternatively until the termination of that contract but, thereafter, only the commercial arch supports specified in this letter were authorized.

At Camp Swift, Tex., about 5 percent of the patients fitted with Arch-O-Graph supports admitted improvement, in contrast to about 10 percent with commercial types, and about 25 percent with custom-made supports. It could scarcely be expected that any but custom-made supports would be satisfactory in view of the variety of conditions for which the supports were prescribed. They required similar variations in the size, shape, consistency, and position of both longitudinal and metatarsal pads, adjustments which were usually beyond the skill of the personnel responsible for the changes. The commercial supports were not satisfactory, but they probably offered the most expeditious and economical method of handling a difficult situation, in which unsatisfactory results were usually built in.

Steel arch supports were almost never used in the Army. They were frequently beneficial in civilian life, but a foot that required such rigid support for the relief of symptoms was not likely to withstand the rigors of Army training.

The Morton type of anterior arch support was also unsatisfactory. This support comes forward under the first metatarsal head and behind the other metatarsal heads, the design being predicated on the theory that most persons with complaints referable to the anterior portion of the foot have short first metatarsal bones. Roentgenologic studies at one clinic showed this to be true in only about one in every six patients examined. Dr. Dudley Morton personally fitted a good many foot complainers at Fort Jackson, S.C., with his anterior arch support, but the results were unsatisfactory in most instances. A number of nurses, however, reported considerable improvement from the use of the Morton insole.

The experience of Camp Swift with the arch support program as related by Maj. Louis W. Breck, MC, may be cited as typical:

> When the hospital was first activated, supports were made of leather by a shoemaker who had had considerable experience in this field. They were not very successful. A little later, when an enlisted chiropodist was assigned to the hospital, he worked under the supervision of the orthopedic surgeon. The leather supports he made for selected patients were somewhat more satisfactory.
>
> Next, Arch-O-Graph equipment was provided, and arch supports were produced with a rubber and cork composition base. If they were carefully adjusted, a few patients were relieved by wearing them, but these men were in the minority, and in spite of the best efforts of all concerned, it was agreed that their supports would not hold up under conditions of active field use. The equipment was, therefore, discarded.
>
> After this experience, the orthopedic surgeon at Camp Swift and his highly competent chiropodist purchased the various components used in custom-made arch supports as blanks from chiropodist supply firms, and the chiropodist made up each arch support individually. This plan took a great deal of time and labor, which were reduced by making the supports in quantity in certain sizes and doing the final finishing individually for each patient. These custom-made supports were far more satisfactory than any other type used during the war at Camp Swift.

At this point (August 1943), The Surgeon General took cognizance of the unsatisfactory results being achieved by arch supports and issued the instructions contained in Circular Letter No. 154 (*21*). Thereafter, only commercial arch supports were provided at this and other installations.

The Army Air Forces experience was, in general, much the same as that just related for Camp Swift. The use of cork insoles made by the Arch-O-Graph technique was particularly disappointing. At one airfield, about 1,700 supports were turned out *each month*, but there were numerous instances of their partial disintegration after long marches, and it was generally agreed that they were not sturdy enough for military use.

SURVEY OF FOOT MEASUREMENTS AND FITTING OF ARMY SHOES

General Considerations

That many of the foot disabilities of World War II were unnecessary is beyond dispute. Without convincing proof, it was assumed that many of them were either induced or aggravated by the footgear issued by the Army and resulted from what was loosely termed "misfitting."

The assumption was in large part correct (*16*). In 1943, the Medical Statistics Division, of the Surgeon General's Office, tabulated 13,050 patients with blisters on their feet of sufficient severity to require confinement to quarters or hospitalization. This was an annual admission rate of 2.81 per thousand strength. The average number of days lost per patient in this group was 6, and the total loss was more than 75,000 man-days. In 7,375 of the 10,490 cases in which the cause of the blisters was indicated, ill-fitting shoes were held responsible. For a true picture of the situation, however, it was necessary to add to the figures cited all the men treated for foot disabilities in dispensaries on a duty status (estimated by some observers to be as high as 20 percent of all dispensary visits), plus the men with less severe complaints who remained on duty without medical attention but whose discomfort decreased their military effectiveness.

Preliminary studies at the Armored Medical Research Laboratory at Fort Knox (*22*) showed that a large proportion of the inductees were wearing shoes that were not in conformity with the dimensions of their feet, chiefly because they were too small. The design of the shoes and the existing methods of fitting explained most of the errors. Existing standards of shoe fitting were by no means precise and were perhaps not appropriate to Army requirements, however acceptable they might have been in civilian practice. Standards presently in use concerned only toe and ball lengths and the fit (snugness) at the vamp (fig. 192). They

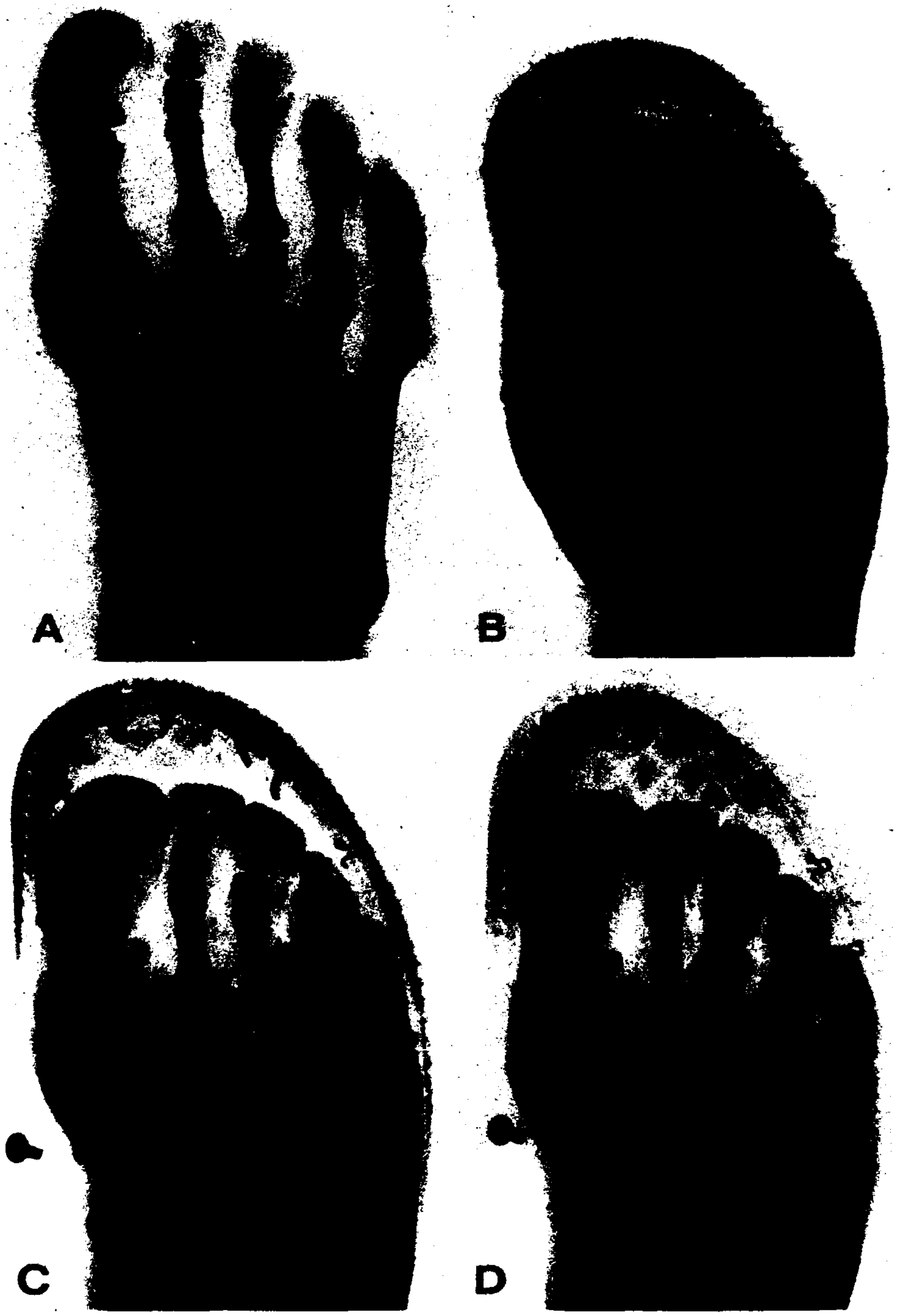


FIGURE 198.—Roentgenologic studies of shod and unshod feet. A. Anteroposterior roentgenogram of unshod right foot. B. Same, with foot in size 9 D shoe. C. Same, with foot in size 10½ EE shoe and sock. D. Same, with foot in size 10½ EE shoe without sock.

FIGURE 198.—Continued. E. Same, with foot in size 10½ EE shoe with box cut away. F. Same, with foot in size 10½ EE shoe, with entire upper cut away. (Freedman, A., Huntington, E. C., Davis, G. C., Magee, R. B., Milstead, V. M., and Kirkpatrick, C. M.: U.S. Army Medical Research Laboratory, Fort Knox, Ky., Project No. T–13. Third Partial Report, 11 Mar. 1946.)

required a standard excess of shoe length over toe length, appropriate precision of fit for the ball length, and glovelike approximation of shoe to foot for the vamp error. The assumption was that, if these requirements were altered, and perhaps one or two other requirements were introduced, the remainder of the shoe would automatically bear the proper relation to the foot at all other points.

This was an incorrect assumption. Roentgenologic and other studies and marching tests at Fort Knox (reported on 12 June 1945 (*16*) and 4 December 1945 (*23*))made it clear that considerably more was involved in the proper fitting of shoes than the assignment of a stated size to a special man (figs. 198–201). Other relevant factors included the approximation of the shoe to the foot at the heel, the arch, the region of the small toe, under the lacing, and several other sites. The precision with which these criteria were then being fulfilled was uncertain, and the nature and frequency of casualties produced by failure to achieve proper foot-shoe relations were not clearly understood. Experience suggested that the establishment of dimensional tolerances between the foot and the shoe depended upon the activity of the wearer, the climate to which he was exposed, the material of which the shoe was made, and the type and

FIGURE 199.—*See opposite page for legend.*

rigidity of its construction. Modification of the size system and of the last proportions of shoes was clearly necessary to achieve proper fitting and substantial diminution of foot disabilities attributable to the footgear worn, but fundamental to these changes was a systematic study of the feet of soldiers, including anthropometric studies.

Materials and Methods

An exhaustive study (Project No. T–13) of the dimensions of soldiers' feet and of the shoes they were wearing was carried out at the Armored Medical Research Laboratory at Fort Knox during 1944 and 1945 (*16, 22–25*). It was conducted by Capt. Arthur Freedman, MC, whose consultants included Major Beath; W. Montague Cobb, M.D., Department of Anatomy, Howard University, Washington, D.C.; Charles Snow, Department of Anthropology, University of Kentucky, Lexington, Ky.; F. M. Gill, Office of the Quartermaster General, U.S. Army; Robert Rhoades, East Bridgewater, Mass.; and Alfred F. Donovan, Rockland, Mass. S. Sgt. Arthur Klein served as photographer and T3c. Everett C. Huntington as statistician. All examinations were made by medical officers. Fifty enlisted men, selected from the troops stationed at Fort Knox, served as measurers, photographers, and scribes. All were carefully trained in the procedures used.

The first report of this study was made on 12 June 1945 (*16*), and subsequent reports were made on 4 December 1945 (*22, 23*) and 11 March 1946 (*24, 25*).

The survey was designed to secure as many measurments as necessary to be representative of the sizes and shapes of the feet of the younger population of the Army. The measurements selected for determination (fig. 202), which were not always those in current use by the shoe trade, were chosen on the basis of Army experience, modified in accordance with suggestions by representatives of the Quartermaster Corps, shoe and last manufacturers, orthopedic surgeons, and anthropologists. A special effort was made to select and define the dimensions to be measured in such a way that the position of each in space could be described. All measurements of length and breadth were, therefore, referred to a set of rectilinear coordinates by orienting the foot before it was measured. Also, whenever necessary, measurements were referred to definable landmarks on the

FIGURE 199.—Plaster models (scale: 1/10-inch) of shod and unshod feet. A. Lateral view of plaster model, showing natural contour of resting foot. B. Lateral view of plaster model of interior of shoe stated to be comfortable. Note upward curvature of toe segment. C. Plaster model of unshod foot viewed from above. D. Plaster model of interior of shoe stated to be comfortable. Note incompatibility of foot and shoe contour. (Freedman, A., Huntington, E. C., Davis, G. C., Magee, R. B., Milstead, V. M., and Kirkpatrick, C. M.: U.S. Army Medical Research Laboratory, Fort Knox, Ky., Project T–13. Third Partial Report, 11 Mar. 1946.)

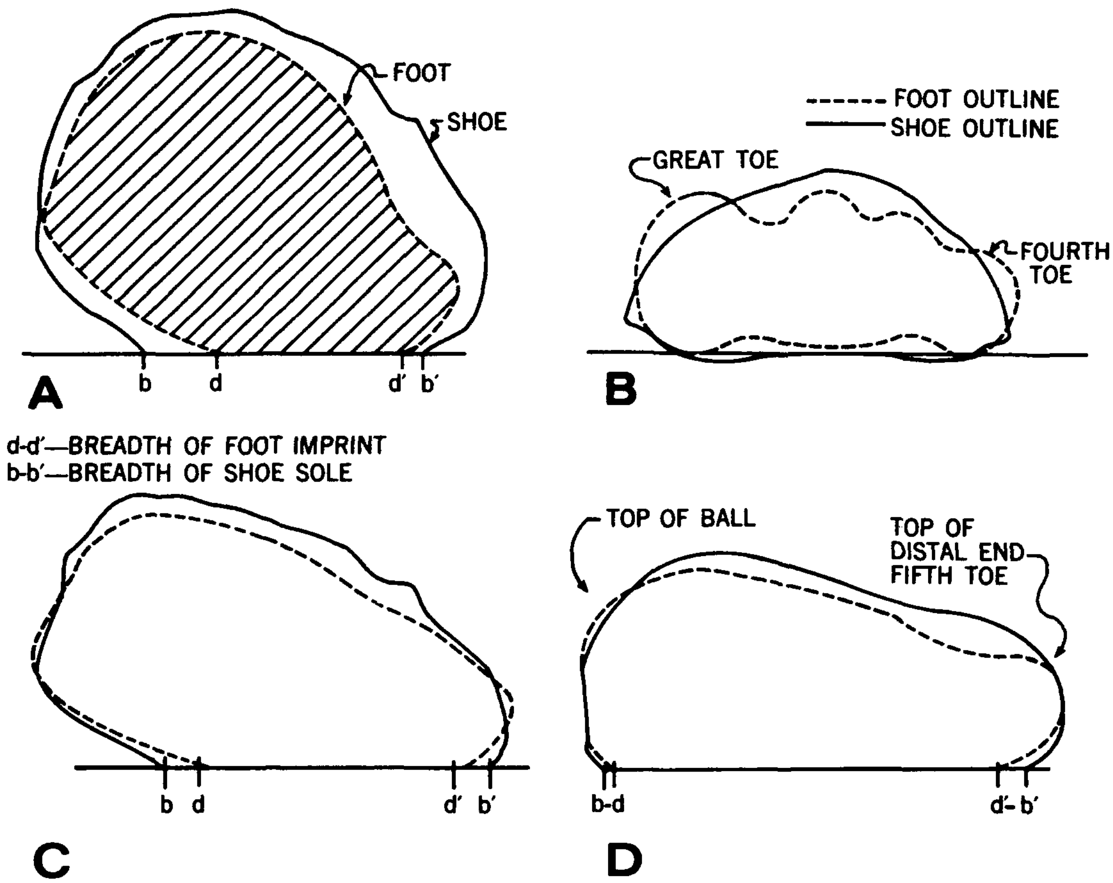


FIGURE 200.—Contour tracings of plaster models of unshod foot and interior of shoe. A. Instep. B. Toes. C. Waist. D. Ball. (Freedman, A., Huntington, E. C., Davis, G. C., Magee, R. B., Milstead, V. M., and Kirkpatrick, C. M.: U.S. Army Medical Research Laboratory, Fort Knox, Ky., Project No. T–13. Third Partial Report, 11 Mar. 1946.)

surface of the foot or to a standard distance from some constant reference point. Two technicians were occupied exclusively with indicating, by ink markings, the exact points on the feet at which the various measurements were to be made (fig. 202). A coding and punchcard system was used to record the data obtained (fig. 203).

All measurements and examinations were made with the men disrobed to shorts, standing relaxed and erect on tables, with the body weight equally distributed between both feet. Subjects were separated by 1- to 2-minute intervals. Data were obtained on an assembly line basis, and it took something less than 20 minutes for a man to traverse the entire line. Special measurements were made on Negro troops, to establish the similarity (or dissimilarity) of physical characteristics with respect to the general Negro population. With the facilities and personnel available, about 200 men could be examined daily.

Every endeavor was made to conduct the investigation on an absolutely accurate clinical, technical, and statistical basis. Repeated checks

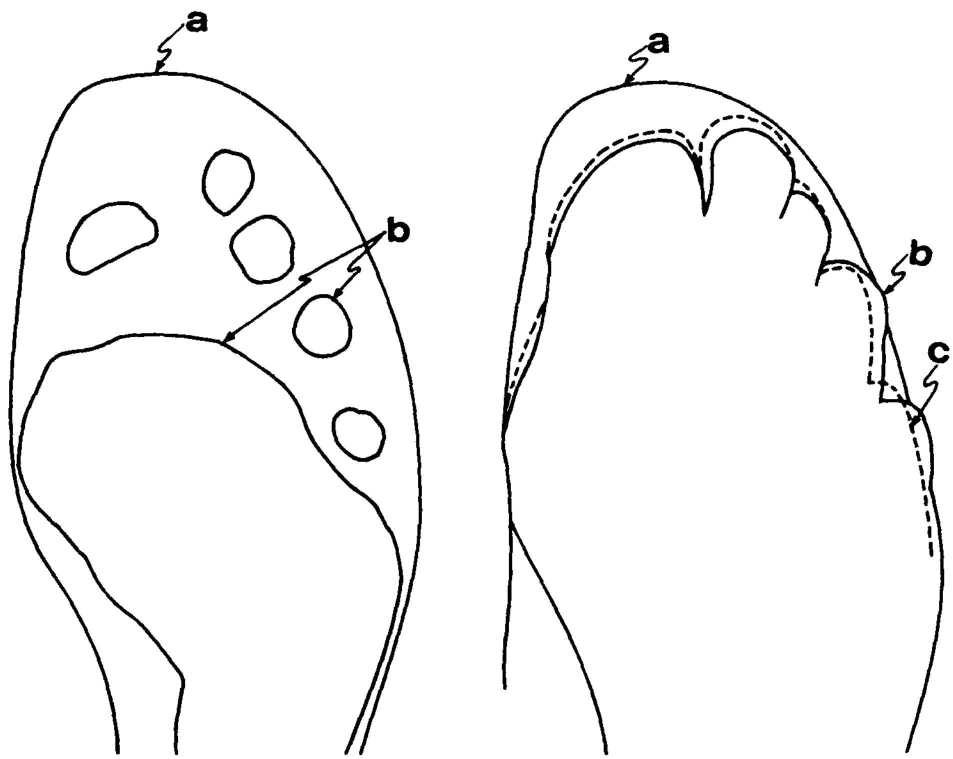


FIGURE 201.—*Contour of foot inside and outside of shoe.* (Left) Tracing of foot from footprint: Sole pattern (a), and tread of unshod foot (b). (Right) Tracing of foot from roentgenogram: Outline of shoe upper (a), soft tissue of unshod foot (b), and outline of foot in shoe (c). (Freedman, A., Huntington, E. C., Davis, G. C., Magee, R. B., Milstead, V. M., and Kirkpatrick, C. M.: U.S. Army Medical Research Laboratory, Fort Knox, Ky., Project No. T–13. Third Partial Report, 11 Mar. 1946.)

were made for accuracy as the investigation progressed. As a further check, and as an indication of how closely measurements could be duplicated by the same technicians, several groups of subjects (199 in all) were sent through the line a second time, as if they were new subjects. The paired records were then compared.

In all, 6,278 white and 1,281 Negro subjects were studied in the course of the investigation, and the final analyses covered 5,575 white and 1,200 Negro subjects. Exclusions from the final count were for reasons running from photographic failures to gross physical defects which would have altered the results. It was believed that the men investigated were representative of the Army population as a whole.

Results and Conclusions

It would be impossible, within the space limitations of this volume, even to summarize adequately the data secured by this study, but certain

DATA SHEET

NAME ______ LAST ______ FIRST ______ INITIAL ASN ______

	NUMBER	AGE YRS.	HEIGHT CM.	WEIGHT KILO.	PLACE ENLISTED	CLINICAL EVALUATION
COLUMN	1-2-3-4	5-6	7-8	9-10	11	12
MEASUREMENT						

DIAGRAM			MEASUREMENT	IBM CARD COLUMN	
N	HEIGHT OF GREAT TOE TIP			13-14	
O	TOE HEIGHT			15-16	
	IDENTIFICATION OF MOST ELEVATED TOE			17	
P	BALL HEIGHT			18-19	
R'	PLANTAR ARCH HEIGHT			20-21	
RY	DORSAL ARCH HEIGHT	RIGHT		22-23	NEGRO:
RY	HEIGHT-SAME	LEFT			INTERORBITAL DISTANCE
	DIFFERENCE			+ − 24-25	NASAL BREADTH
Q	OUTSIDE BALL HEIGHT			26-27	LIP THICKNESS
T	ANKLE LENGTH			28-29	FACIAL HEIGHT
	POSTERIOR HEEL CONTUOR			30	FACIAL BREADTH
M	BALL GIRTH	RIGHT		31-32	UMBILICAL GIRTH
M	GIRTH-SAME	LEFT			CHEST GIRTH
	DIFFERENCE			+ − 33-34	
S	ANKLE GIRTH			35-36	
V	LOWER LEG GIRTH	RIGHT		37-38	
AC	FOOT LENGTH	LEFT		39-40	
AC	LENGTH-SAME				
	DIFFERENCE			+ − 41-42	
A	BALL LENGTH	RIGHT		43-44	
A	LENGTH-SAME	LEFT			
	DIFERENCE			+ − 45-46	
C	TOE LENGTH			47-48	
B	5th TOE LENGTH			49-50	
U	OUTSIDE BALL LENGTH			51-52	
KL	BREADTH OF 3 FORWARD TOES			53-54	
J	FOOT BREADTH (DIAGONAL)	RIGHT		55-56	
J	BREADTH-SAME	LEFT			
	DIFFERENCE			+ − 63-64	
	ANGLE—LINE I TO LINE J			57-58	
	CONTOUR AND ORIENTATION O TOES (BY TEMPLATE)			59-60	
DE	BALL BREADTH ON HORIZONTAL	RIGHT		61-62	
D	WIDTH—CENTER LINE TO MEDIAL BORDER	RIGHT		65-66	
	FLARE (RATIO D/DE			67-68	
GH	BREADTH OF INSTEP			69-70	
G	PROPORTION OF SOLE IN CONTACT WITH GROUND			71	
	LATERAL FOOT CONTOUR (BY TEMPLATE)			72	
F	HEEL BREADTH			73-74	
X	INSTEP GIRTH			75-76	
AC'	FOOT LENGTH (STICK)			77-78	
I	OUTSIDE BALL LENGTH DIAGONAL			79-80	

A

FIGURE 202.—Coding system used, and measurements taken, in Fort Knox study of feet and shoes of soldiers. A. Data sheet.

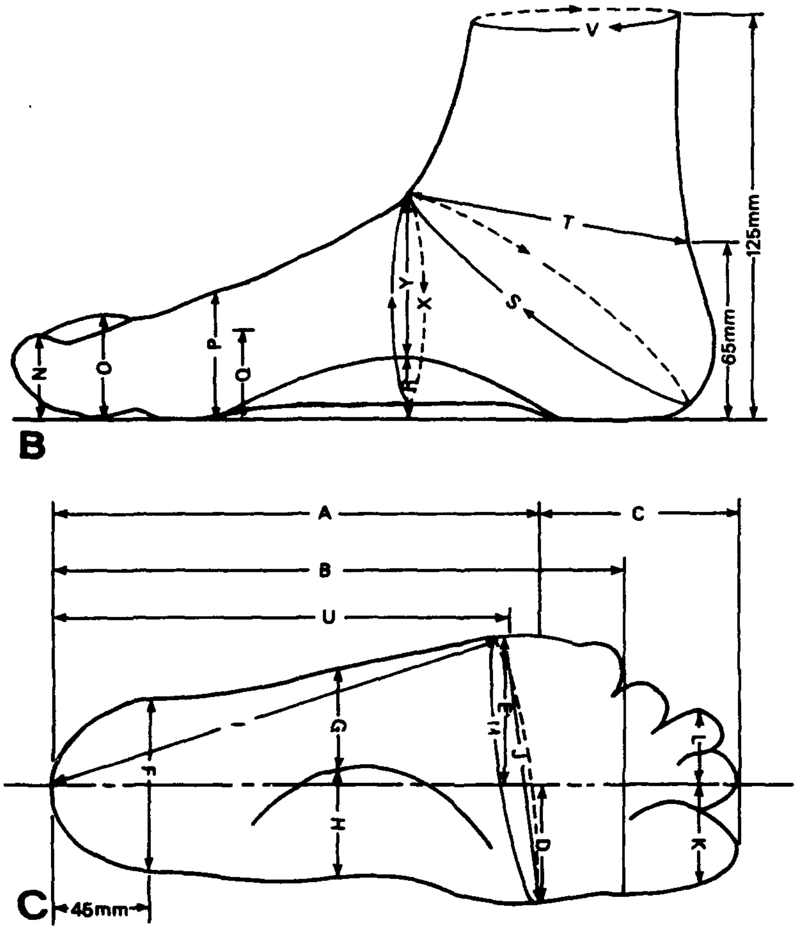


FIGURE 202.—Continued. B. Lateral aspect of foot. C. Plantar aspect. (Freedman, A., Huntington, E. C., Davis, G. C., Magee, R. B., Milstead, V. M., and Kirkpatrick, C. M.: U.S. Army Medical Research Laboratory, Fort Knox, Ky., Project No. T-13. Third Partial Report, 11 Mar. 1946.)

conclusions pertinent to the fitting and wearing of the army shoe in relation to the feet it was supposed to fit might be mentioned:

1. All clinical examinations were made by competent medical officers, after preliminary tests had shown that their judgments on individual cases were reasonably uniform. The objectives of these examinations were to identify foot types visually and to describe characteristics of structure and shape that might indicate the existence of nonaverage dimensions.

In the men examined, it was found that 69.55 percent of the white subjects and 52.76 percent of the Negro subjects had grossly normal (that is, nonexceptional) feet. A low arch was the most frequent deviation from normal among both groups, but the incidence of deviation among Negroes was more than twice that among whites. Clinical estimate of a

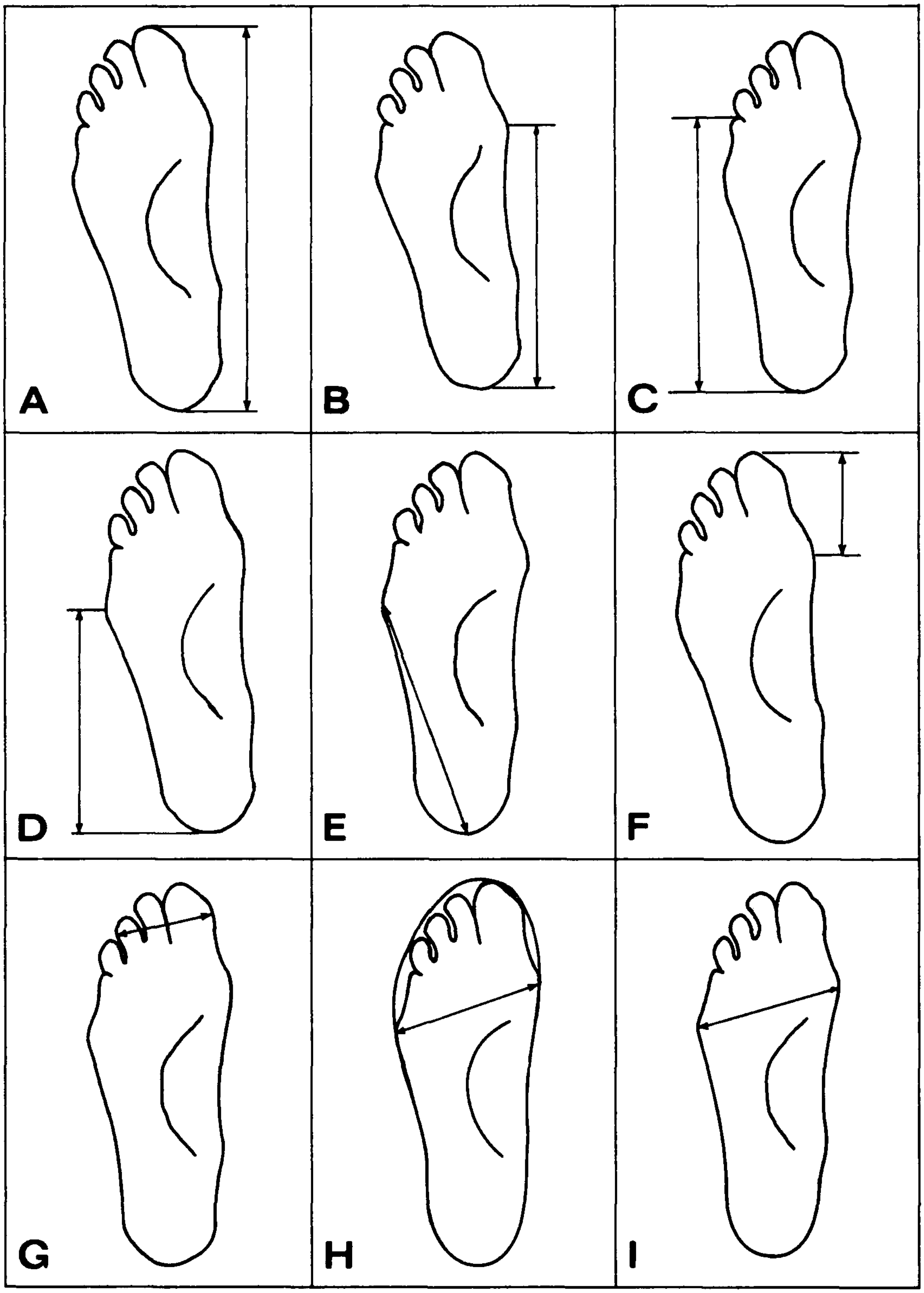


Figure 203.—*See opposite page for legend.*

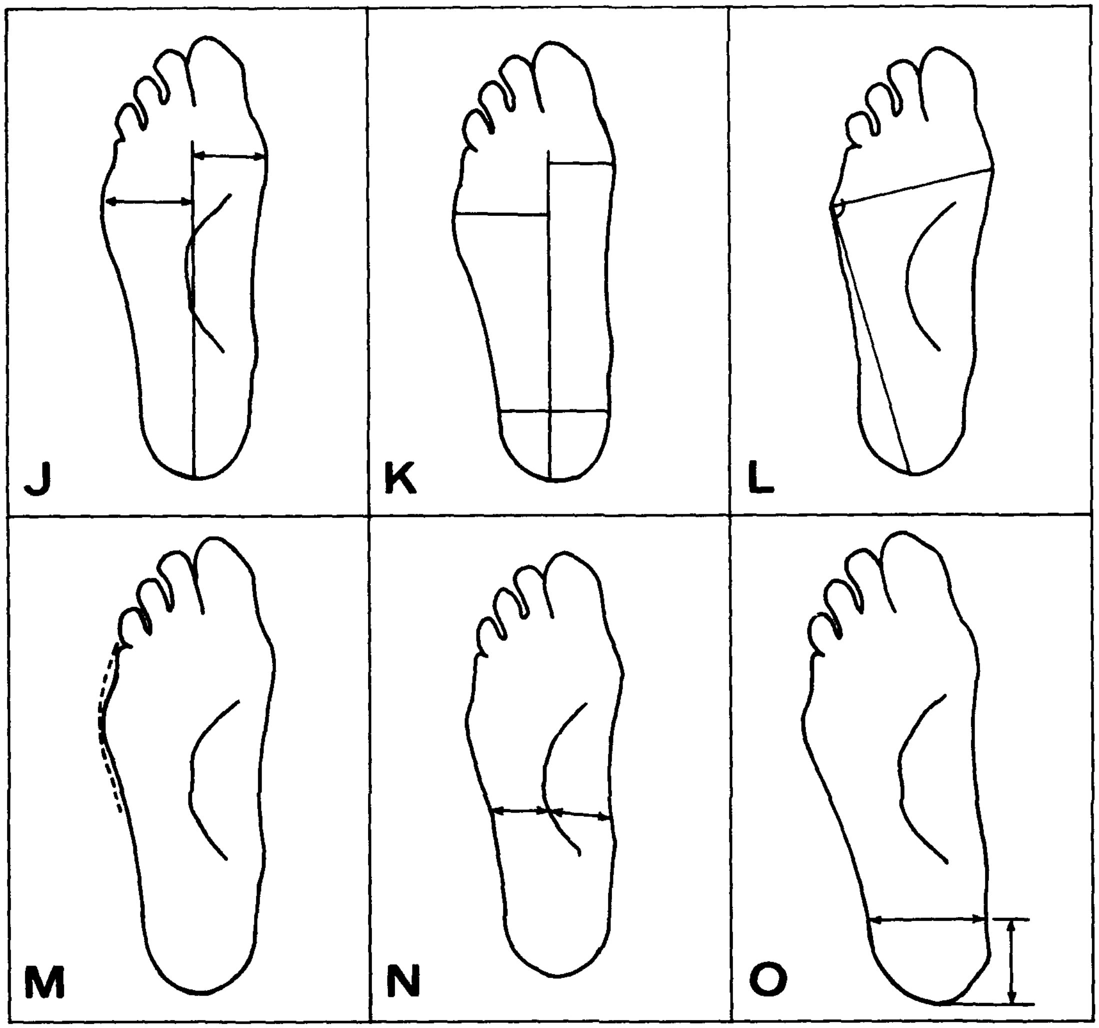


FIGURE 203.—Details of most important measurements made in Fort Knox study. A. Foot length. B. Ball length. C. Length of fifth toe. D. Outside ball length. E. Same, diagonal. F. Toe length. G. Breadth of three forward toes. H. Anterior curvature and orientation of toes. I. Foot breadth, diagonal. J. Same, horizontal. K. Foot flare. L. Angular orientation of metatarsal heads. M. Lateral contour of foot. N. Breadth of instep. O. Breadth of heel.

low arch was made on the basis of the apparent height of the dorsal surface of the foot and the plantar arch curvature. Judgment on a visual basis was apparently subject to error, for many times, the measurements taken did not substantiate the visual impression.

The length and breadth of the toes appeared to bear little if any relation to the actual height of the arch, though these dimensions seemed to influence clinical judgments.

On the basis of these and other observations, it was concluded that foot typing by clinical examination rests on extremely insecure grounds.

The actual measurements were not consistently in accord with clinical judgments, which was an insurmountable obstacle in any attempt to put typing to clinical use.

2. Important measurements for which various correlations were carried out, are shown in figure 203.

For each group of widths measured, distributions were studied for eight other selected dimensions; a very wide spread was revealed. However the measurements were grouped, a large number of individuals still remained whose various dimensions failed to approximate a central tendency, even for dimensions assumed to be as closely related to each other.

It might be assumed that individuals whose feet were exceptionally long or exceptionally broad or exceptionally short or narrow might also have other measurements uncommonly large or small. The size grading of shoes was in part predicated on this assumption: With an increase in length and width, other measurements were increased accordingly. This was another incorrect assumption. The correlations existed only infrequently. The data showed that the various dimensions of the foot may be highly independent of each other and that a consistent increase or decrease of one measurement in relation to another is not the rule. This is an observation of great importance in the sizing of shoes.

3. The experience of 35 unselected soldiers at Fort Knox showed that they could usually wear service shoes in hot or temperate climates without blisters, calluses, corns, ingrown toenails, or painful feet when the shoes were properly fitted. When such lesions developed, they promptly healed, without any change in the men's duty assignments, if larger sized shoes were issued. These observations were in agreement with Munson's earliest test of a march of 379 men in properly fitted shoes (p. 133). Other studies of variations in the feet of men carrying out short marches in a hot environment showed no consistent pattern of size change sufficiently impressive to warrant any conclusions at all with regard to the effect of such activity on shoe fitting.

4. These studies showed requirements for successful fitting to be:

a. Conscientious measurements of the foot by an interested fitter who was encouraged to take sufficient time with each man.
b. Development of a measuring device corresponding to army sizes.
c. Modification of regulations for the use of measuring devices.
d. Frequent checking of new and rebuilt shoes for accuracy of sizing.
e. An adequate supply of shoes in the size range needed.

Size tariffs based on contemporary Army experience were not reliable. The Army practice was to issue shoes too short and too narrow. When substitutions were necessary, they should always have been—but frequently were not—in the direction of increased width, never shorter length, since in the World War II shoe under study, width decreased with length.

5. Modification of existing regulations for fitting implied:

a. Complete disregard of the soldier's own opinions concerning size. The civilian shoes he was wearing when he was inducted were probably too small.

b. Realization that feet to be fitted might be functionally abnormal because incorrectly fitted shoes had been worn in civilian life. The assignment of trained chiropodists at fitting stations to note these points would save many dispensary visits later. The first fittings, it should be noted, should always be at a central depot, never a company supply room, in order to provide an adequate range of sizes and trained supervision of the fitting.

c. One expedient for better fitting would be the use of a piece of felt between the lacing and the tongue, to provide additional thickness against which the laces could be tightened.

6. It was highly doubtful that there was any consistent increase in the size of the feet with training, for the fundamental reason that full development of the feet is universally achieved by the time even the youngest recruits are inducted. Remeasuring of the feet of 389 soldiers at Fort Knox (fig. 196) after 17 weeks of basic training showed that about 25 percent had an increase of half a size in the heel-to-toe length. Changes in width were divided between increases and decreases and were not more than one-eighth of an inch in any instance.

The significance of these changes was not understood, but it was concluded that until it was, it might be well to refit all men at the completion of their basic training.

7. Studies were made on 30 carefully selected men who marched a total of 400 miles over a 32-day period, exclusive of Sundays and holidays, over concrete roads and improved and unimproved dirt roads, at 119 paces to the minute, for a net marching time of 4 hours and 20 minutes daily. All their gear, as well as their clothing, was specified.

Eight men were excluded for various reasons during the course of the test. On the 20th day, the remaining 22 men, who were by then throughly conditioned, were fitted with smaller service shoes on one foot and larger shoes on the other. The shoes were reversed on the 22d day; and on the 28th day, either they were reversed again or new shoes were issued, one still smaller and one still larger.

In many instances, the sizes of shoes worn in this test did not correlate with the sizes indicated by the Clarke measuring device.

In the 22 conditioned subjects, who underwent 286 man-days of testing, only 36 lesions developed on their feet, none of great severity, and only 18 severe enough to require that the men drop out for part of a day's march. Shoes that were too small were being worn when 30 of the 36 lesions appeared.

This experience suggests that tolerance for larger sizes of shoes is greater than is generally realized and that the number of sizes provided in World War II (220) was really not necessary. One precaution was necessary: When larger sizes were worn, the throat of the shoe had to be padded, to maintain approximation of the heel to the shoe. If a means of

attaching the padding to the shoe had been provided, larger sizes of shoes would have had a still wider field of usefulness.

8. The deficiencies of the World War II service shoe fell into two categories, (a) size and shape and (b) materials and construction. The studies of footgear worn by marching troops had made it clear that every phase of boot design is dependent upon, and in turn influences, every other phase, and that change in one component must take into account the effect of the change on all other components. It was, therefore, the opinion of those participating in this investigation that the best results would be achieved by designing an entirely new boot, from basic principles, though this conclusion should not be taken to indicate that the boots used in World War II were entirely unsatisfactory.

It would also be a mistake to assume that changing the last of the shoe then in use would have corrected all the errors in fitting. These errors, as already pointed out, derived only in part from faulty design. Faulty issue played a prominent role, and if that error was not corrected, no modification of the last could be expected to produce any improvement.

Recommendations

Of a number of suggested changes in the design of the army shoe, the following were considered most important from the orthopedic standpoint:

1. A change in the design of the last to make a broad enough sole for the foot to rest on. It should not be necessary to wedge the forefoot into the front of the shoe to secure a satisfactory fit.

2. The use of more resilient material for the upper and of a different type of closure at the throat. These changes might produce a shoe that fitted securely at the ankle while affording abundant space for the metatarsals and phalanges in the forefoot.

3. Better requirements in respect to shape. Circumferential measurements do not express the shape requirements of a properly fitted shoe. Shoes in use in World War II seemed to be manufactured on the principle (fig. 190) that the foot is "a relatively amorphous mass that can be accommodated if sufficient cubic volume is made available inside the shoe." This investigation showed that what is needed is a shoe whose sole is as broad as the widest part of the foot over it and whose upper leather is shaped to accommodate the dorsal as well as the ventral toe and ball diameter (figs. 200 and 201).

4. Changes to provide for tapering of the toe of the shoe. The World War II army shoe, with an excessively curved tip combined with arching of the leather over the toes, confined the toes, and the only way to minimize the effect of this construction was to issue an otherwise needlessly long shoe in order to provide space for the smaller toes.

5. Change in the shaping of the upper leather at the shank. The need for significant shaping of the leather at this point, to provide a close fit under the arch in order to support the shoe, was never demonstrated. Such construction made it difficult to fit a man with a depressed astragalus and scaphoid, who had flat feet in the anatomic if not in the functional sense.

6. Changes in the design of the lasts. The lasts used in World War II provided a shoe with the broadest diameter at the ball of the foot. It was not necessary to measure many feet in the Fort Knox investigation before it was clear that, in a large number of men, the broadest diameter of the foot was forward of this point.

The design of a last at this time was predicated on a systematic increase of every dimension with an increase in any other dimension. This principle increased the diameter of the heel with every augmentation of the circumference of the foot at the ball. Again, it took only a limited number of observations to show that this practice did not correspond with the proportions of the human foot.

All of these observations were taken to indicate strongly the need for a series of accurate measurements before any new lasts were designed. The Fort Knox study had made these basic measurements available. Whatever success was being achieved by the fitting practices in use at the time could be attributed in large part to the apparently great tolerance of the human foot for shoes of improper size.

7. Change in the shape of the shoe. The World War II shoe rested almost flat on the ground when it was new. When it was worn, it almost invariably turned up more or less at the toe (fig. 199B). Since no objections were raised to this change in shape, it was proposed that the altered shape be made standard, with such associated advantages as shortening of the upper dimension longitudinally from toe to vamp and with less likelihood of creasing of the leather of the vamp, which was a fairly frequent cause of abrasions of the tops of the toes.

PRINCIPLES AND PRACTICES IN FITTING

Army shoes in World War II were considered to be designed and fitted properly by a negative criterion; namely, that they did not diminish the effectiveness of troops under difficult field conditions. The controlled Fort Knox study was apparently the first to investigate the possible harmful effects of ill-fitting shoes. Preliminary observations suggested that many foot disabilities could be promptly corrected by the issue of larger shoes and proper socks.

Standards of fitting of army shoes were not expected to give optimum results for all men. Some observers estimated that, while these shoes were superior in many respects, they were appropriate for not more than 70 percent of the men who wore them. They were not made to measurement

of individual feet, and fitting practices, therefore, had to be adapted to the shoe. The designs and practices undoubtedly represented the accumulated experience of the shoe trade and were more or less satisfactory for less stringent civilian requirements. They were simply adopted by the Army, which had never made a systematic evaluation of its own fitting practices.

The techniques currently in use required certain compromises. Thus, encasement of the forepart of the foot might be necessary to avoid looseness at the throat for men with low arches and small ankles. Frequently, the dimensions of a man's two feet were not the same, and the practice of averaging the sizes and fitting him accordingly did not fit him correctly. Once the shoe was fitted, the propriety of the fitting rested upon (1) the compatibility of equivalent foot and shoe measurements, (2) palpation of the shoe by the fitter, (3) the sensations of the wearer, and (4) such subjective criteria as the roentgenologic appearance of the foot inside the shoe if this particular check was available.

The various foot measuring machines in use in the Army were not really measuring machines. As they were then calibrated, they provided information only concerning the shoe size to be issued. This information might be incorrect for army use, since these measuring devices were designed to provide a snug fit. Also, these machines gave information about only three dimensions, which meant that reliance had to be placed on the proper proportioning of the last to assure that other portions of the foot fitted in the shoe as they should.

Army regulations concerning fitting (p. 784) were also predicated on a snug fit. From this situation, certain errors arose:

1. Shoes were sensibly too tight.
2. Shoes were not appreciated as being excessively tight and, for this reason, they were productive of disability when they were worn.
3. Shoes did not produce disability in temperate climates, but it could be demonstrated roentgenologically that they compressed and distorted the shape of the foot, and for this reason, they could contribute to the occurrence of cold injury.
4. Shoes that provided abundant space for, and no pressure on, the forefoot might be sensibly loose because snugness at the ankle was insufficient to maintain the integrity of the foot and shoe as a unit in walking.

The sum of these observations was that a shoe with the desirable properties of providing abundant space for the forepart of the foot, while at the same time hugging the ankle and arch closely, did not exist for most men in the Army in World War II.

In World War I, a survey made in 1918 of 42,000 men at several army camps showed that only 15.2 percent were wearing properly fitted shoes; 81.7 percent were wearing shoes that were too short and the remainder, shoes that were too long (*2*). An earlier survey, by Maj. Edward L. Munson, MC, reported the experience of a colleague who found, in one series of measurements, almost precisely similar data; only 16.6 percent

of the men were wearing properly fitted shoes, and most of the remainder were wearing shoes that were too small (*1*).

In World War II, a study at Fort Knox of 579 trainees just arrived from reception centers in which they had received their first army shoes less than 3 weeks before showed that only 183, less than a third, were wearing correctly fitted shoes. The most prominent tendency was the issuance of shoes half a size too small, but more than 15 percent were wearing shoes a whole size too short. The sizes were in general considerably smaller than those stipulated in Army regulations, even when the feet were measured without socks. Moreover, measurements of 57 pairs of service shoes made by 22 different manufacturers revealed dimensions considerably smaller than the Brannock size system implied. The discrepancies were not considered to indicate errors in manufacture but (1) defects in the plan of systematic shoe sizing and (2) failure of the measuring device in use to correspond to the shoe sizing plan. Finally, in only 45 of the 57 pairs of shoes examined were the right and left shoes of approximately identical size. In the other 12, the differences ranged from one-eighth to five-sixteenths of an inch.

In the 1918 study, the explanation of fitting errors was (1) inexperienced fitters; (2) ignorance and vanity on the part of the inductees; (3) discrepancies between the designation of shoe size and the actual dimensions of the foot; (4) incomplete stocks, leading to substitutions; and (5) fitting on the basis of civilian conditions of use (*2*).

In World War II, there were different explanations for errors of fitting:

1. Failure of the fitters to issue shoes according to the measuring devices, possibly because of the haste with which many fittings were accomplished.
2. Failure of the fitting devices to agree with the size dimensions of the shoe.
3. Inappropriateness of the size and shape of the army shoes for men who would spend most of their time standing and marching.
4. The use of conventional civilian fitting standards under Army conditions.
5. Resistance of soldiers to wearing sizes of shoes that did not agree with what they had worn in civilian life.[3]

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[3] According to the Director, Clothing and Organic Materials Division, U.S. Army Natick Laboratories, on 2 February 1966, "Post-war Boots are made over new last developed from data contained in study 'Foot Dimensions of Soldiers,' by Armored Medical Research Laboratory, Fort Knox, Kentucky, dated March 1946. Cold weather footwear (combat boots) are provided with insulation (wool fleece) hermetically sealed between inner and outer layer of latex to provide protection down to −65° F. Tropical boots incorporate outsole for increased traction, combination leather and fabric upper for cooling and drainage of water and are flexible for walking."

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Part VII

REGIONAL FRACTURES: SPINE AND LOW BACK

CHAPTER XXVIII

Injuries and Lesions of the Spine and Low Back

Mather Cleveland, M.D., and *Alfred R. Shands, Jr., M.D.*

Section I. Civilian-Type Injuries

This chapter, which is devoted to injuries, diseases, and syndromes related to the spine and lower back, does not include spinal cord injuries or such conditions as herniated nucleus pulposus, which are discussed in detail in the two volumes in this historical series devoted to neurosurgery (*1, 2*). Special attention is devoted in the second of these volumes to the unprecedented advances made in the care and rehabilitation of paraplegics in World War II.

Problems referable to the back during this war fell into two major groups. The first group consisted of fractures of the spine at various levels, which frequently resembled those observed in civilian life or which were the result of war wounds. Motor vehicles, including the jeep, the tank, and other vehicles used in war, greatly increased the incidence of simple and compound compression fractures of the spine. Airplane and glider accidents and paratrooper service had the same effect. Minefields in all theaters of operations produced many dorsolumbar compression fractures as vehicles passed over them.

A detailed discussion of fractures and dislocations of the cervical, dorsal, and lumbar spine in military service is omitted since the mechanism of sustaining these injuries as well as their treatment differs little if at all from their origin and treatment in civilian practice. A few illustrations are appended as examples of how these problems were encountered and solved by military orthopedic surgeons (figs. 204–208).

The second group of problems referable to the back in World War II comprised what was frequently termed the "low back syndrome." It is discussed in some detail in the following pages.

Section II. The Low Back Syndrome

GENERAL CONSIDERATIONS

Incidence

The second group of problems referable to the back in World War II was generally known as the low back syndrome. It was perhaps the com-

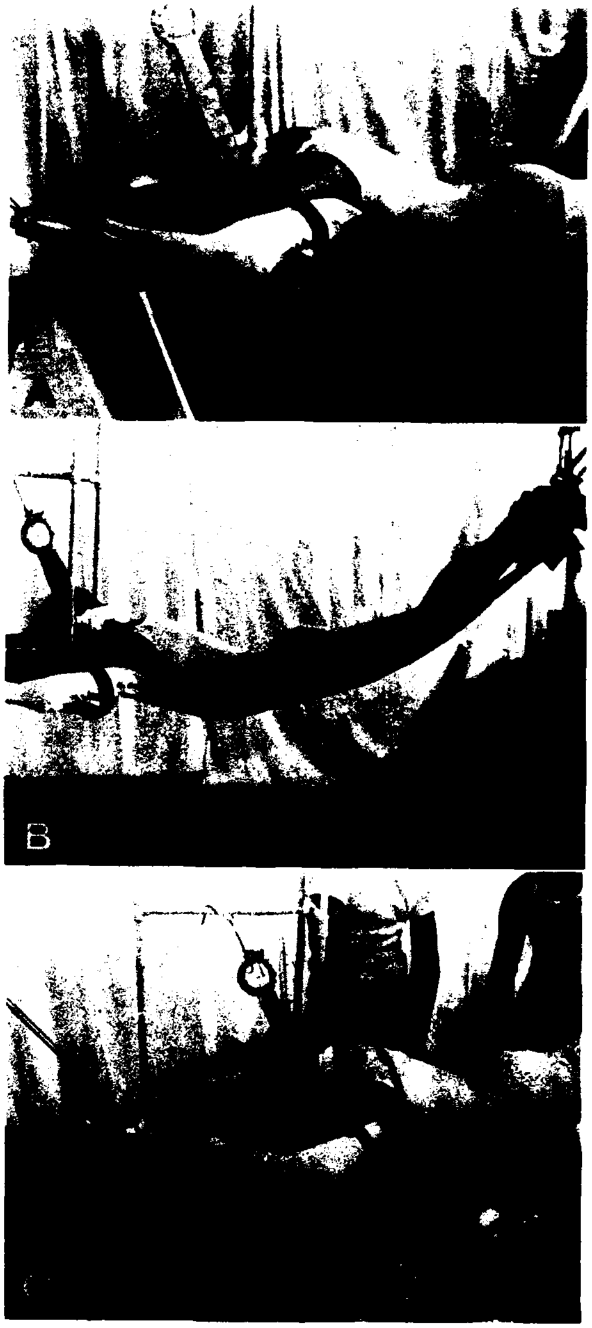

FIGURE 204.—Application of plaster-of-paris jacket in compression fracture at dorsolumbar junction of spine. A. Patient in position before suspension. B. Patient slung in hyperextension before application of plaster of paris. C. Application of plaster-of-paris jacket with spine hyperextended. The accessibility of the entire spine is readily seen.

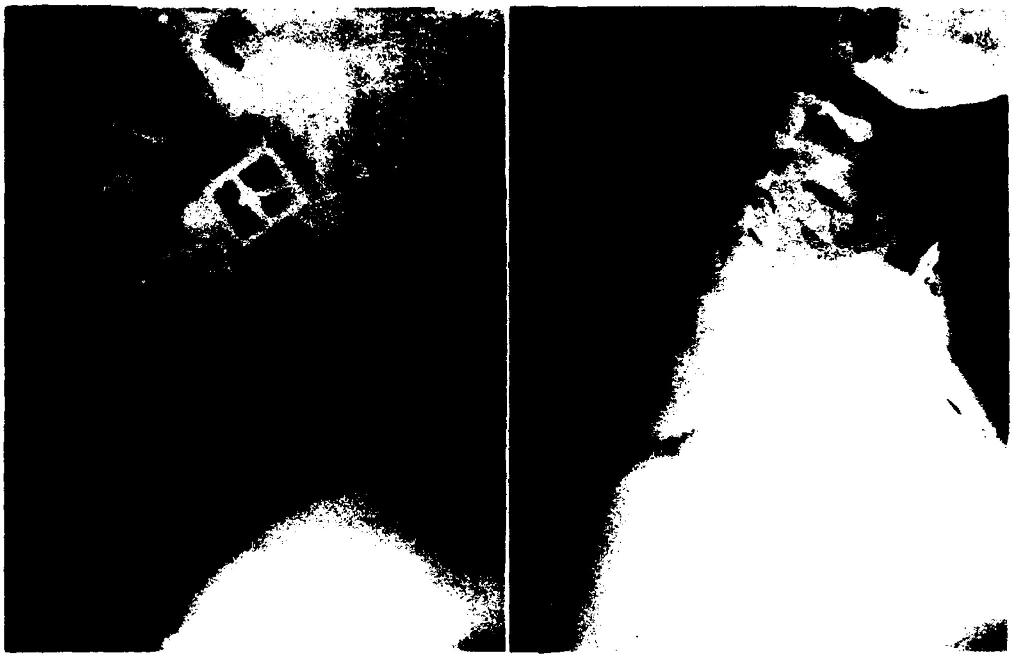

FIGURE 205.—Compression fracture of fifth cervical vertebra. (Left) Lateral view of cervical spine showing fracture. (Right) Lateral view of same with cervical spine held in hyperextension by plaster-of-paris jacket. The compression of the fifth cervical vertebra is improved.

monest of all problems encountered during training, and later in service. Acceptable statistics do not exist for it, but there is no doubt that if it did not exceed foot complaints in frequency, it ranked next to them, and it was, if anything, a more persistent and more serious source of trouble.

Various estimates of the incidence were presented at the AAF (Army Air Forces) conferences held in October 1943 (*3*). They ranged from 15 to 35 percent of the outpatient clinic load and from 10 to 30 percent of the ward load. At intervals, the numbers of patients treated for this complaint in outpatient dispensaries almost overwhelmed the staff. At one processing center, 22 percent of the orthopedic examinations per thousand men were for low back pain. At one clinic, 50 percent of the men with back pain examined in the outpatient department had to be hospitalized for further investigation. At a large infantry training center in the South, there were 320 hospital admissions for low back pain in a total of 47,900 admissions, 0.66 percent. In one general hospital, there were 258 admissions for this cause in a total of 6,800 admissions, 3.8 percent. In another, there were 2,500 admissions for low back pain over a 2-year period, with 175 admissions for this cause over one 2-month period. It was estimated that, up to the time these AAF conferences were held, chronic back complaints constituted about 25 percent of the orthopedic caseload in AAF clinics and hospitals, and that two-thirds of them existed prior to induction.

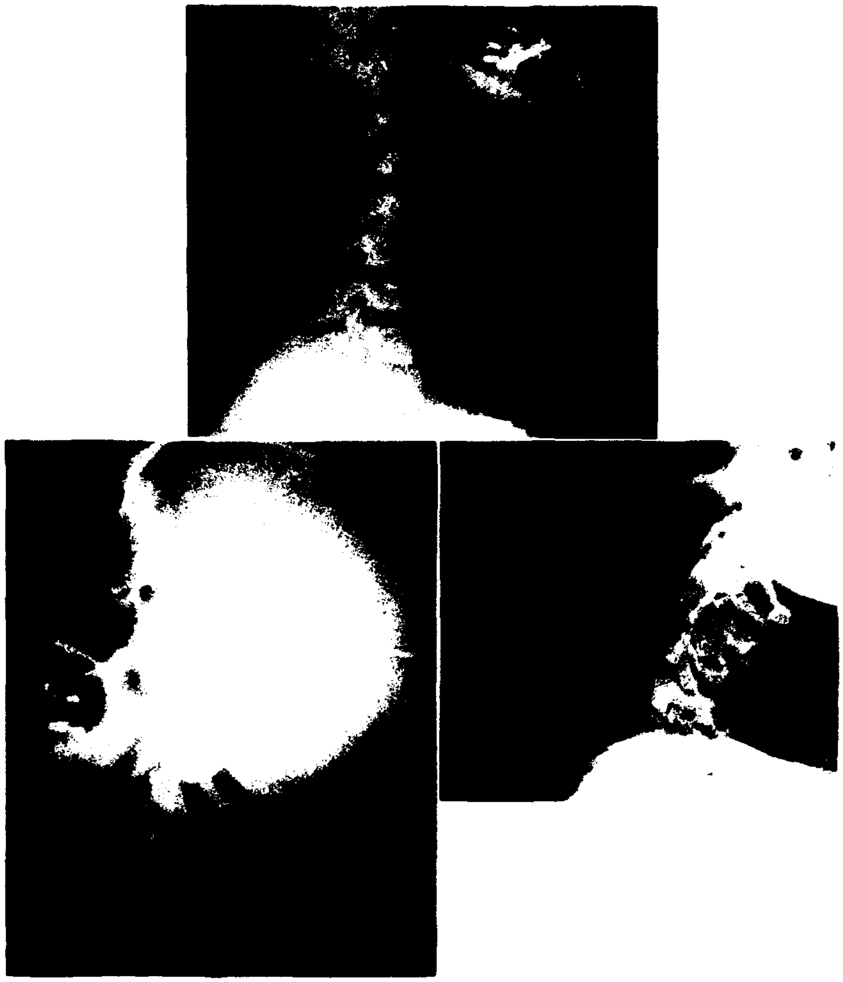

FIGURE 206.—Forward dislocation of upper cervical spine. A. Lateral view of cervical spine showing forward dislocation of fourth cervical vertebra on fifth. B. Lateral view of same spine, showing dislocation reduced, with normal alinement of vertebrae. C. Lateral view of same spine held in hyperextension by plaster-of-paris jacket, with maintenance of reduction of dislocation.

The experience of an individual orthopedic surgeon is illuminating. In a survey Colonel Shands made personally before these conferences, covering 729 orthopedic diagnoses in 691 patients at the AAF station hospital, School of Applied Tactics, Orlando, Fla., during March and April 1943, he found 172 complaints (23.6 percent) referable to the back (*4*). Of these complaints, 114 existed before induction. Over the 2-month period in question, 152 patients with similar complaints were examined in the orthopedic clinic of this hospital. In 99 instances, almost two-thirds of the number, the difficulties were of long standing. At the time of his survey, Colonel Shands had 24 patients with chronic back complaints

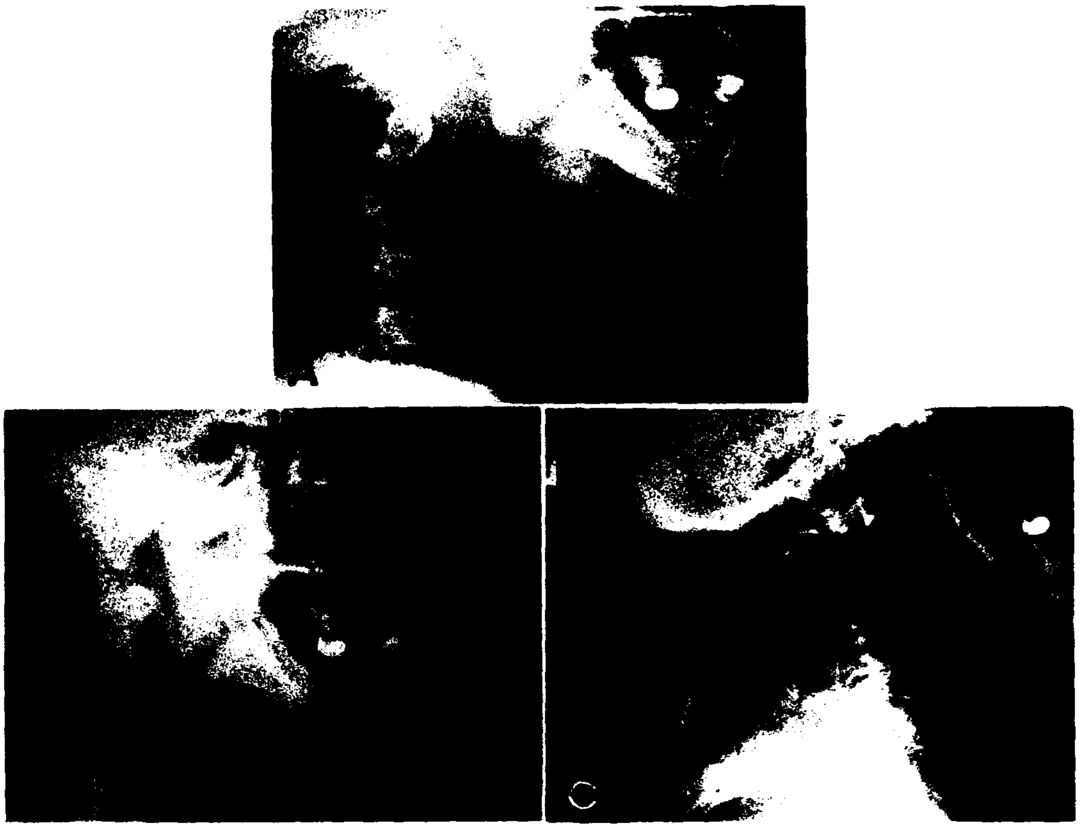

FIGURE 207.—Anterior dislocation of cervical spine. A. Lateral view of cervical spine, showing anterior dislocation of second cervical on third. Wires are seen applied to teeth to immobilize fractured mandible. B. Lateral view of same cervical spine after 2 weeks of skeletal head traction. Treatment has failed to reduce completely the anterior dislocation at the level of the second and third cervical vertebrae. C. Lateral view of same cervical spine after operation. The dislocation is now completely reduced. Note wire suture from spinous process of second cervical vertebra to that of third. The head and cervical spine are immobilized by a plaster jacket.

among 55 patients in two wards under his control (44 percent). These figures are entirely consistent with those just cited.

Diagnosis and Therapy

The specific diagnosis of the low back syndrome was elusive. Even when the workup was careful and thorough, it was often difficult, particularly for medical officers who had only recently entered service, to evaluate both the patient and his symptoms. In all probability, many patients were hospitalized unnecessarily because of indecision on the part of inexperienced officers who had not yet come to understand this particular problem and its military implications. It taxed the ingenuity of well-trained orthopedic surgeons and neuropsychiatrists, and it is small wonder that

FIGURE 208.—Splint devised at station hospital, Pendleton Field, Oreg., with forehead band and occipitomastoid support on vertical thorax bar. (Left) Posterior view of soldier wearing well-padded splint applied to thoracic and cervical spine. Note support afforded by splint to occipital and mastoid regions. (Right) Lateral view, showing forehead band. This splint definitely immobilizes the cervical spine in some hyperextension.

the average medical officer, with little or no military experience and often limited civilian experience, was also uncertain. It was interesting to observe how recommendations for hospital admissions fell off as experience with back complaints increased.

All the evidence indicates that the treatment of low back complaints in the Army was not satisfactory. It was thought at the beginning of United States participation in the war, when the problem promptly became manifest, that the opportunity of observing and managing large groups of men would shed some light on the difficulty. It did not, as is evident in the discussions at the AAF conferences in October 1943 (*3*). One reason for the clinical confusion in the Army was the confusion in the voluminous literature that existed on the subject, in which there was practically no unanimity of opinion. To the end of the war, the low back syndrome remained a difficult condition to treat, and the results of treatment were unrewarding. Comparatively few patients made complete re-

coveries, and even fewer could be returned to full field duty, particularly if they had been hospitalized. Some methods of treatment were actually harmful in that they kept the soldier's attention centered on his back. In these circumstances, there was usually a large functional overlay, and the patients either ceased to be useful as soldiers, or were fit only for limited duty.

It is worth pointing out again, to complete the picture, that a combat soldier's training was not easy. Young, healthy men had tremendous physical reserves and recuperative powers to draw on, and most of them honestly used these abilities to the fullest. Those with less vitality, those with less will to achieve, and many relatively older men, long since out of condition—if, indeed, they were ever in it—could have their military usefulness limited or destroyed by the low back syndrome, even when it was chiefly functional. There were many bona fide complaints, of course, but there were also many instances in which men used their symptoms to improve their assignments, to make their work lighter, or to have themselves separated from service.

ADMINISTRATIVE CONSIDERATIONS

The soldier with a complaint of low back pain was first seen at sick call by the unit surgeon. If the surgeon was capable and interested, he could immediately secure a great deal of pertinent information about the patient and his problems. The company officer could tell him what kind of soldier the man was, and a look at the sick book would reveal or exclude the existence of a tendency to "ride" this or other complaints as a means of escape from work or perhaps from the Army.

The next stop along the medical administrative road was the orthopedic clinic of a station hospital, which, as just noted, was sometimes overwhelmed by the influx of men with backache. The orthopedic surgeon, like the unit medical officer, could gain a great deal of useful information from a carefully taken history, particularly in the many cases in which nothing physical was found to confirm the complaint of low back pain.

A properly run orthopedic clinic in a station hospital screened out for investigation and therapy the soldiers who did not need hospitalization. From the station hospital, a smaller number of men were evacuated to the general hospital, where they would be either rehabilitated after therapy and returned to duty or discharged after receiving maximum hospital benefits. The general hospital was the repository of formidable diagnostic and therapeutic problems, among which, for all its seeming unimportance, the low back syndrome deserved to be classed.

Its importance is evident in certain administrative measures taken to handle these patients. At Cushing General Hospital, Framingham, Mass., for instance, all new patients with low back symptoms were examined at a weekly low back conference, participated in jointly by orthopedic and

neuropsychiatric personnel, at which individual programs of management were outlined.

At Lawson General Hospital, Atlanta, Ga., two wards were devoted to patients with back complaints. They were under the charge of a single officer, who correlated his orthopedic diagnosis and therapy with the neuropsychiatric aspects of the case whenever this was indicated. This plan so greatly increased the administrative duties of this officer that he had to be provided with extra help to leave him enough time for his professional duties. Medical Administrative Corps personnel and Women's Army Corps personnel were most helpful.

At several general hospitals in the First Service Command, wards were organized for back disorders and were operated collectively by orthopedic, neurosurgical, roentgenologic, and physiotherapeutic personnel. Originally, this seemed an excellent plan, and in theory, it was. Actually, it proved unwise. The patients discussed their histories and complaints with each other and found them similar, even when the medical officers did not. Their subjective symptoms became worse, and their response to treatment became less satisfactory. The wards were, therefore, disbanded, a step which in itself, of course, solved no problems.

ETIOLOGIC FACTORS

The role of herniated nucleus pulposus as a cause of low back pain could not be divorced from its orthopedic origin by the surgeons who first saw the patients and who diagnosed and treated them, though in the Army, operations for this condition were perfomed by neurosurgeons; in civilian practice, most such operations are done by orthopedic surgeons. The question soon became academic in the Army, in which the impermanence of the results of operation led to its restriction to carefully selected patients, usually key personnel (*1*).

Otherwise, and exclusive of acute trauma, infection and instability of the low back due to congenital variations at the lumbosacral joint were the most usual causes of legitimate complaints of backache in young males.

Classification of patients with low back pain under etiologic factors showed no consistency at all (*3*). In one station hospital, 25 percent of 304 such patients were classified under lumbosacral strain; 15.7 percent under arthritis; 6 percent under psychoneurosis; 4.4 percent under spondylolisthesis; and 1 percent under herniated nucleus pulposus. In contrast, 29 of 79 patients admitted to another hospital were classified under acute muscular or ligamentous strain, 21 under lumbosacral and sacroiliac strain, nine under psychoneurosis and hysteria, seven under arthritis, four under scoliosis, two under herniated nucleus pulposus, and one under spina bifida. No attempt at classification was made in the remaining cases in either series.

At the AAF conferences in October 1943, several proposed classifications were advanced (*3*). One classification was:

1. Acute back strain or sprain of recent origin from lifting or sudden twisting.
2. Longstanding pain in the lower back associated with sciatic symptoms.
3. Similar pain not associated with sciatic symptoms.

Another proposed classification divided low back pain into arthrogenic, myogenic, neurogenic, and psychogenic types. The officer who proposed it at the AAF conferences stated that he had encountered the glove type of hypalgesia of the lower extremities in more than 200 patients, who had been observed on an average of 3 months, and whose complaints he regarded as psychogenic. A number of other officers stated that they had frequently observed hypesthesia in patients with low back pain.

A uniform classification of these patients would have been helpful in planning a program for their management, but opinions concerning the nature of the condition varied so widely that such a classification was never practical.

Postural Factors

At the 12th Annual Assembly of the American Academy of Orthopaedic Surgeons in 1944, three of the instructional courses were devoted to the painful back, with particular reference to the role of faulty body mechanics in the "military lame back" (*5–7*). Capt. Paul A. Pemberton, MC, also discussed the effect of malposture (*8*):

> From childhood to adult life, he said, flexion of the hips is habitual and requires, in the standing position, an increase in lumbar lordosis for the trunk to be maintained upright. As there is a greater range of extension in the lumbosacral joint than in other segments of the lumbar spine, the greatest postural defect occurs at this point. No natural forces exist to decrease the resulting lumbar lordosis, and many factors tend to increase it. Because the extensor muscles of the lumbar spine are stronger than the flexors, any pathologic process that causes a protective muscle spasm of the back results in increased extension of the lumbosacral joint. Subsequently, there is actual shortening of the extensors, the lumbosacral joint is permanently held in full extension, the flexors of the spine are weakened by overstretching, and these flexors are forced to work at a mechanical disadvantage. This sequence of events furnishes the background for the chronic low back pain that follows minor injuries, such as twisting, or lifting heavy weights, when the lumbosacral joint is pulled forcibly into hyperextension from a position of almost complete extension. In time, the same mechanism keeps the joint in such a position that the ligaments are always under tension and pain becomes continuous. Arthritis and fibrositis are frequent complications.

Many men were observed in the Army with sound backs, whose posture had always been poor but who had never before had backache. Their difficulties were explained on the ground of fatigue. The mechanics of the pain were the same as those just outlined except that habit was responsible for the complete extension of the lumbosacral joint.

The history of these patients was typical. They complained of pain on standing in one position for a considerable time, on sitting still for a considerable time, and when they were fatigued. They were usually relieved by movement. Pain might also occur on prolonged exercise. Sometimes, it wakened the patients at night. Again, relief was usually accomplished by movement. The explanation of night pain was simple: Normal muscle tonus protects the back fairly well for the first 4 or 5 hours of sleep. Then relaxation is so nearly complete that the joints of the back sag and pain occurs in the strained ligaments.

Neuropsychiatric Factors

In a great many cases, the histories obtained from patients with low back symptoms pointed at once to their neuropsychiatric origin (*9*). Backache was only one of many subjective complaints, including headaches, dizzy spells, palpitation, nervousness, and many other symptoms which the patient readily agreed to if they were suggested to him until, said one surgeon, the soldier seemed "actually to be a corpse standing before the medical officers."

Inquiry into the previous history also often took a typical turn. The man had held a large number of jobs, none of them for very long. Occasionally, he was receiving compensation for a specific injury or accident and hoped that it would be carried on while he was in service. Almost invariably, his backache had begun years before, often without injury. Civilian physicians had seldom been consulted.

Symptoms varied from mild backache to acute pain, with or without radiation into the lower extremities, and it was extremely difficult to prove that the man was not suffering the pain he complained of, even though objective signs might be completely lacking.

Hospitalization was sometimes recommended in this sort of case, so that the medical officer might become acquainted with the patient and evaluate his personality. This policy was time-consuming, but in many instances, diagnosis and treatment depended upon how much credence could be placed upon the patient's history and complaints.

Patients with neuropsychiatric tendencies were usually no better and no worse from the standpoint of their complaints after a few weeks of rest, heat, massage, and directed exercises. They were frequently worse from another standpoint: Those with mild backache, treated over long periods of time without relief, often become chronic complainers. If, while in the hospital, they were thrown into contact with other patients with more severe back pains, their own complaints frequently became worse, too, with nothing objective to explain the increased symptoms. This course of events was frequently observed, and a solution for it was never found. In any event, such men could never be returned to full duty. Before recommending hospitalization, therefore, particularly prolonged hospitali-

zation, for patients with the low back syndrome, the medical officer had to reflect upon the effect the proposed plan of treatment might have upon the patient's attitude and morale.

This chain of events happened so often that some orthopedic surgeons thought psychiatric examination essential for the diagnosis and treatment of all patients with chronic back pain. There was no doubt that backache was a refuge for a rather large number of men who were inadequate personalities and who failed to fit into the pattern of Army life. They had probably failed (or would have failed) similarly in civil life, but in it, they were more sheltered and protected, and the demands upon them were probably less than in the Army. The Consultant in Orthopedic Surgery, Fourth Service Command, expressed the opinion that, if careful rounds were made on the neuropsychiatric section of any Army hospital, the incidence of backache in the patients classified as neuropsychiatric would probably be 80 percent or more.

Good cooperation between the neuropsychiatric and orthopedic surgery sections in all hospitals reduced the hospital admissions of men with chronic back pain and eliminated unnecessary visits to the outpatient clinics.

A problem that was discussed at practically every orthopedic conference during the war concerned (1) the differentiation of malingerers from psychoneurotic personalities and from men who simply exaggerated minor symptoms in a desire to be relieved of disagreeable duties or to be discharged from the Army and (2) the differentiation of these groups from honest patients with real symptoms. It was essential that the malingerer be detected and weeded out as promptly as possible because of his bad effect on the morale of those with whom he associated. When his status as such was established, administrative or disciplinary procedures were instituted.

Diagnosis of conversion hysteria was often difficult, though some spectacular results were obtained with sodium amytal (Pentothal sodium). In one Negro battalion at Camp Maxey, Tex., hysterical backache gave rise to such bizarre manifestations that a moving picture was taken to show their amazing collective behavior and gait (*10*).

DIAGNOSTIC CONSIDERATIONS

The aim of the diagnostic routine in the low back syndrome was to distinguish from each other (*11*):

1. Patients with functional complaints ranging from malingering to hysteria. This group consisted of individuals "whose back complaints [were] a feature of a psychogenic pattern of evasion on either a conscious or subconscious level (sometimes on both levels simultaneously)" (*9*).
2. Patients with organic disabilities.

History-Taking

The best history was secured by indirect questions, since it not only provided the facts desired but also, as already pointed out, threw light upon the patient's mental attitudes, especially in regard to his service and duties. Leading questions were sedulously avoided. Inquiries about the pain complained of included its onset; location, severity; the circumstances under which it began and under which it recurred; and the relation to it of posture, activities, changes in the weather, and visceral functions.

If the complaints antedated induction, the inquiry covered the kind of work done in civilian life (desk, factory, labor), the loss of time from work because of the disability, the compensation for time so lost, recreational activities, previous medical consultation, and previous treatment. If the man, as a civilian, had repeatedly had medical care, it could be assumed that he had some true disability, whether functional or organic, and this fact was of value in interpreting his present complaints.

If the history was brief, factual, moderately (but not too well) integrated, if the patient used lay terms, and if he did not seem suggestible, it was likely that his complaints had an organic basis (table 13) (*11*). If the history was introspective and was poorly or imperfectly integrated, if the patient used medical terms, and if he readily assented to symptoms suggested by the examiner, the condition was likely to be functional.

Physical Examination

Most examinations of the spine were disappointing, even when the history suggested moderately severe disability. The explanation was, in part, the depth of involvement, which made it impossible to inspect directly or to palpate the structures that might be involved. A thorough, careful examination was essential; the more the examiner could rely upon objective findings and the less he was obliged to rely upon subjective evidence, the more likely was his diagnosis to be accurate.

Spinal curves.—The examination began with a study of the patient's posture, including the spinal curves. Army regulations (*12*) permitted induction with as much as 2 inches of deviation from the midline. Lateral deviations were less apt to be symptomatic than deviations in the sagittal plane. They suggested congenital hemivertebrae, idiopathic scoliosis, and protective muscle spasm following acute lesions (*11*).

An increase in the dorsal curve might be due to underlying arthritis, tuberculosis, or adolescent round back resulting from juvenile epiphysitis. The latter condition had usually become manifest before induction. If symptoms due to any of these conditions developed during service, or if they recurred, separation was the general policy.

TABLE 13.—*Differential diagnosis of low back syndrome in relation to patient's history*

Features	Suggestive of organic origin	Suggestive of functional origin
History of injury	Definite traumatic incident	Indefinite traumatic incident or absence of trauma.
	Recent trauma	Trauma remote in time.
	Trauma adequate to give rise to symptoms.	Trauma of trivial character.
	Trauma result of patient's own actions.	Trauma result of someone else's actions or negligence.
Nature of pain	Localized to one or more definite areas.	Indefinite, diffuse or widespread.
	Subject to exacerbations and remissions.	Continuous and unremittent.
	Aggravated by adequate, especially prolonged, strains (standing, bending, lifting, reaching, coughing, turning in bed).	Aggravated by inadequate strains, or brief exertions (light efforts connected with details).
	Radiation, if present, toward thighs or flanks in low back complaints; toward neck and shoulders in upper back complaints.	Bizarre radiation.
Manner of recital	Factual, brief; moderately, but not too well, integrated.	Circumspect, introspective; poorly or perfectly integrated.
	Lay terms used	Medical terms used.
	Not suggestible	Ready assent to symptoms suggested by examiner.

Source: Fuldner, R. V.: Diagnosis of Minor Back Disabilities. Mil. Surgeon 95: 228–232, September 1944.

Flattening of the lumbar curve often indicated severe disability, especially when it was associated with muscle spasm. Lordosis suggested spondylolisthesis, congenital dislocation of the hips, flexion contractures of the hips, a secondary reaction to a deforming lesion of the dorsal region, or simply poor posture.

Inequalities in the length of the legs up to an inch or more did not, in themselves, explain back pain. Occasionally so-called sciatic scoliosis might be induced, but as a rule, unusual attitudes or gaits suggested at least a partially functional origin.

Muscle spasm.—Palpation for muscle tonus was carried out first in the erect and then in the prone position. Experience was necessary to recognize both normal and abnormal tonus in both positions.

Muscle spasm was considered a fairly accurate index of disability, and many orthopedic surgeons were wary of making a positive diagnosis in its absence. It could represent involuntary or voluntary splinting, or a degree of voluntary splinting superimposed on underlying involuntary splinting.

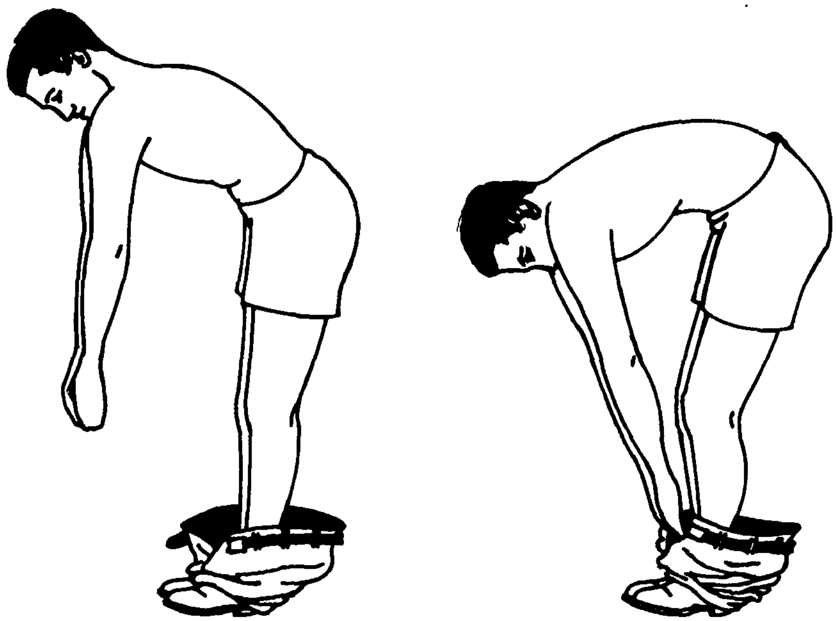

FIGURE 209.—Pants test, designed to check on limitation of mobility of spine. (Left) Inability of patient to flex spine at request of examiner. (Right) Absence of limitation of mobility when patient pulls up his pants at his own volition, while examiner is apparently not looking. (Fuldner, R. V.: Mil. Surgeon 95: 228–232, September 1944.)

When muscle spasm was the result of organic disability, the muscle tonus was greater than normal in both erect and prone positions. When spasm was present and marked in the upright position but disappeared in large part in the prone position, a voluntary component was suggested. When the splinting was voluntary, all the devices useful in the examination of nervous patients had to be invoked, including a reassuring manner, warming of the hands, diversion of the patient's attention, and initiation of the examination at some remote point.

When muscle spasm had existed for some time, secondary contracture, or shortening, of the fibrous tissue elements in and about the muscle was often present. When the spasm was low in the back, the contracture could occur in the lumbodorsal fascia and in the anterior, posterior, and lateral parts of the fascia lata, including its gluteal ramification.

Three tests were of value in demonstrating these contractures:

1. The average subject, from the erect position, with his knees straight, should be able to bring his fingertips to the floor or to within 2 or 3 inches of it. The pants test (fig. 209) was a useful check on the actual limitation present (*11*). If time permitted, the examiner could always learn a good deal about the patient by watching his movements as he undressed.

2. Differentiation between contractures of the thigh and the back could be accomplished by having the subject assume the sitting position, in which the thighs are relaxed.

3. The examiner should be able to flex the leg of the normal subject, with the knee in extension, to within 5 to 10 degrees of vertical. Dorsiflexing the ankle indicated whether the contracture was primarily in the lower leg or in the hip and thigh.

Tenderness.—When the examination for tenderness was carried out, it was well to have the patient lie with his face toward the examiner. His expression during manipulations frequently furnished a useful clue. It was also useful to mark the points of tenderness complained of at the beginning of the examination and verify their constancy later.

Localization of tenderness to one area was characteristic of a number of organic lesions. Obliteration of the sign by injection of Novocain (procaine hydrochloride) was of both diagnostic and therapeutic value. Both back and leg pain originated, more frequently than was generally realized, as a reflex phenomenon in localized points of infection or trauma. If the pain was increased with the first insertion of the needle into the tender (trigger) point and then disappeared as the injection proceeded, it was presumably referred from the trigger point, and management could be worked out on that assumption.

Diffusion of tenderness, especially when localization was vague and inconstant, was suggestive of functional disorders. Complaints of excessive tenderness, withdrawal of the part from the examining hand when the skin was lightly touched, and gross limitation of motion unaccompanied by muscle spasm helped to differentiate patients with functional complaints from malingerers. Another useful observation was the refusal to flex the spine in the erect position but no hesitancy in coming to a sitting position from a prone position.

Physical findings associated with poor posture.—In instances of the low back syndrome caused by poor posture, there was one constant physical finding; namely, full extension of the lumbosacral joint when the patient was standing. There was no movement in this area when he bent backward. There might be demonstrable movement in hyperextension in the lumbar spine, and care had to be taken to differentiate it from movement in the lumbosacral joint. Movement in this joint was not difficult to detect if the examiner placed his forefinger on the spinous process of the fourth or fifth lumbar vertebra and his thumb on the sacrum. If there was no movement in the lumbosacral joint, the finger and thumb tended to approach each other when the patient bent backward.

Two other findings were almost always present in this group of cases:

1. The forward tilt of the pelvis, which could be measured accurately by first determining the angle of inclination of a line through the top of the symphysis pubis and the lumbosacral joint and then comparing the angle with known normal variations. Such precision, however, was not necessary. Forward tilting of the pelvis was always accompanied by protrusion of the lower abdomen, and, conversely, when the lower abdomen was prominent, there was always an associated increased pelvic tilt.

2. In this type of low back pain, the most common point of tenderness was over the depression between the fifth lumbar spinous process and the first sacral spine. There was practically always tenderness at this point in mechanical lumbosacral strain, and there was frequently tenderness at it in individuals with postural errors, even if they did not have backache. There was also frequently tenderness medial to the posterior superior iliac spines at the outer attachments of the iliolumbar ligaments. This finding indicated strain on these ligaments, which was often incorrectly termed "sacroiliac strain."

Other, more complicated tests had no place in a busy dispensary, since the diagnosis of postural backache could be made on the basis of the three factors discussed; namely, limitation of extension of the lumbosacral joint, increase in the pelvic tilt, and localized lumbosacral tenderness.

Roentgenologic Examination

Roentgenologic examination of the lumbar spine, sacroiliac joints, pelvis, and hip joints was routine in all complaints referable to the back. Anteroposterior films were supplemented by lateral views of the lumbar vertebrae and by lateral spot films at the lumbosacral level. Oblique views of the apophyseal joints were taken on indications, as were special studies of the sacroiliac joints.

If the roentgenograms were negative, it was usually possible to rule out such conditions as arthritis, tuberculosis, old fractures, and neoplasms. and such congenital anomalies as spondylolisthesis; unilateral or bilateral sacralization of transverse processes of the fifth lumbar vertebra; asymmetrical facets, lumbarization of the first sacral segment; and vertebral epiphysitis. Roentgenograms were useful in planning the therapy of these conditions, but were of little value in planning the management of nonspecific low back problems.

A number of techniques of roentgenologic examination in low back pain were devised during the war, but in spite of their ingenuity, these techniques did not lend themselves to wartime use (*13*).

Therapeutic Response

The patient's response to therapy was always a diagnostically useful point. A disability based on any recognizable pathologic factor practically always responded in some measure to intelligently directed treatment. Functional disorders usually did not. The response to detail assignments in nonhospitalized patients, and to a reconditioning program in the hospital, graduated according to the patient's ability, often clinched the diagnosis. The observations of the physiotherapist in the patient's unguarded moments were also very useful.

DIFFERENTIAL DIAGNOSIS

It was a common experience, as already noted, for subjective complaints referable to the back to be unaccompanied by somatic evidence to substantiate them. Among the specific causes for the low back syndrome which had to be differentiated were:

1. Spondylolisthesis. This condition could be present for many years, indeed, for the patient's whole life, without manifestations until some minor trauma occurred or until the stress and strain of military life, with its increased activities, became too great for the defective structure to tolerate. A surprising number of men with this condition were observed in the Army, though actually the explanation is simple, that many soldiers had backache and that many more roentgenograms were taken to investigate them than would have been taken in civilian practice. Only infrequently was spondylolisthesis considered aggravated by service, and a true line-of-duty-yes was seldom warranted.

Several comprehensive studies of the roentgenologic aspects of spondylolisthesis appear in the volume on radiology in the history of the U.S. Army Medical Department in World War II (*14*).

2. Fibrositis. This condition was usually accompanied by muscle spasm and followed by limitation of joint motion because of the development of periarticular adhesions. The combination of phenomena resulted in chronic pain in the lower back. Tenderness was not usually localized to one joint or one muscle.

3. Arthritis. This was the commonest of the demonstrable causes of low back pain. In its milder forms, it was often attended with a degree of pain and disability entirely out of proportion to the apparent activity or severity of the arthritic process. In some instances, it was transient, and changes in the joints apparently were not permanent, even though symptoms continued. In other instances, roentgenograms showed hypertrophic changes in the joints of the spine. As always, the presence of degenerative changes in the spine did not necessarily indicate that they were symptomatic.

Mild acute arthritis of the spine was associated with protective spasm of the lumbar muscles, with increased lumbar lordosis. The arthritis might clear up entirely, but hyperextension of the spine remained and was always potentially, if not actually, symptomatic. The degenerative changes affected ligaments and capsule as well as bone and cartilage, and caused more or less limitation of motion. In the lumbosacral region, motion was painful unless such a posture was maintained that the joint was held in the center of a limited range. In such cases, the back pain could be caused by malposture rather than by arthritis per se, and a great deal of relief could be obtained by correction of the defective mechanisms.

Limitation of joint motion was usually the first demonstrable sign of arthritis of the spine. It was more readily demonstrated than true muscle spasm, and was often present before roentgenologic changes were evident. If the patient with arthritis was carefully observed, he would be seen, after flexion of the spine, to extend it, and then to extend the hips and dorsal spine. Such a patient was obviously guarding joint motion in the lumbar region and could be assumed to have something more seriously wrong with him than a simple mechanical low back strain.

4. Intraspinal lesions. Their presence was usually suggested by such findings as atrophy of the muscles, spasm and shortening of the hamstrings, sensory changes, absent or unusual reflexes, and a positive straight-leg-raising test. Sciatica was often present also. Neurologic consultation was necessary in the face of these findings.

5. Sacralization and lumbarization, which were found in relatively large numbers of patients with low back pain.

6. Interapophyseal isthmus defects.

MANAGEMENT

At the AAF conferences in October 1943 (*3*), a number of medical officers expressed the opinion that every hospital should have a definite routine of diagnosis and management in the low back syndrome. Such a routine was never worked out. To the end of the war, there was never full agreement on how this syndrome should be treated, for the unhappy reason that most methods of therapy were entirely unsuccessful.

The most widely used program was rest on a hard mattress for varying periods of time, combined with sedation as indicated; physical therapy (infrared heat or diathermy and massage); and exercises under direction. At Camp Swift, Tex., simple lumbosacral strain was treated in this manner, with the patient kept in the flexed position in the acute stage (*15*). Postural training was also instituted, to obliterate excessive lumbar lordosis.

Many medical officers believed that, if the simple routine just described did not produce improvement in 2 or 3 weeks, further disposition must be considered, in the form of limited duty or separation from service on CDD (Certificate of Disability for Discharge). No doubt one of the explanations of the failure of this conservative regimen was the limitation, by regulations, of the time patients could be kept in station hospitals.

Other therapeutic methods employed, most of them with no very striking results, were:

1. Manipulations. These had to be carried out very carefully, in very carefully selected cases, and only by trained personnel.
2. Plaster immobilization for varying periods of time.
3. Local injections of Novocain, as already described. This was not a popular method.
4. A supportive corset or brace.

Mild arthritis, when it was treated by standard measures, was entirely compatible with selective military activity. Acute arthritis required bed rest; a high-caloric, high-vitamin diet; sedation; bilateral leg traction; directed exercises; and, sometimes, plaster jackets or braces. Patients with severe arthritis were separated from service as promptly as possible on CDD.

The key to successful treatment of low back strain due to poor posture was correction of the basic cause, which was hyperextension of the lumbosacral spine. Physical therapy, application of liniment, strapping, and similar measures were not advisable. If improvement occurred, cure was attributed to them, and if the symptoms recurred, there were usually requests for more treatment of the same kind even though it could not possibly be permanently effective.

Instead, the patient who was properly treated was made to understand that he was responsible for his own progress and that the essence of therapy was to flatten his back, retract his abdomen, and decrease his pelvic

tilt. Instruction and practice were time-consuming. Trained medical officers trained enlisted men, who then demonstrated the necessary techniques to the patients, who were taught special exercises and were also taught how to sit, stand, and sleep. Once they understood the principles, most of them found that no more effort was required to stand correctly than to stand incorrectly.

Surgery has an extremely limited field in the low back syndrome and allied conditions in civilian life, and a far more restricted role in Army medicine. No matter what the operation, selection of cases had to be done with great care. If the patient had a tendency to exaggerate his symptoms, surgery might increase the tendency and make him worse than he was before. Even so simple a procedure as removal of a painful coccyx was properly undertaken only in mentally and emotionally stable individuals.

Such highly specialized procedures as section of the fascia lata or piriformis muscle, stripping of the gluteus maximus from its upper attachment or origin, or excision of articulating transverse processes were not acceptable Army procedures. They were ingenious, but they failed to meet the criterion of success in all military operations; that is, the return of the patients to duty.

Arthrodesis was seldom permitted. In the Fourth Service Command, for instance, the orthopedic surgeon who proposed to perform it was required to produce incontrovertible evidence of the need for it, and practically without exception, the existence of low back pain before induction was not considered to meet that criterion. If congenital deformities existed, such as spondylolisthesis, or if there were beginning arthritic changes, operation was permitted in carefully selected cases in which a line-of-duty factor was thought to be present. Arthrodesis with cortical and cancellous bone, or with cortical bone alone, usually brought a large measure of relief from pain in such cases.

SPECIAL STUDIES

Fort Jackson Station Hospital

At the Fort Jackson Station Hospital,[1] during 1942 and 1943, 320 patients with back complaints were admitted to the orthopedic service in a total of 47,908 admissions, slightly over half of 1 percent. These figures do not include any instances of so-called myositis or arthritis not

[1] The material for this report was collected by Maj. (later Lt. Col.) Leon J. Willien, MC, and Maj. Patrick C. Doran, MC. The report was made by Col. Mather Cleveland, MC, then Consultant in Orthopedic Surgery for the Fourth Service Command, as part of a symposium on back pain at an Army Air Forces conference in Durham, N.C., in December 1943. The report included the study on low back pain by Maj. Dudley W. Smith, MC, presented later in this chapter. The arrangement of (1) a unit medical officer, (2) an orthopedic clinic at a large infantry post, (3) a station hospital at the same post, and (4) the low back pain situation in an established general hospital makes an orderly presentation of events in the history of this condition (*16*).

associated with trauma, both of which were treated on the medical service.

The results of the investigation and treatment of these 320 men were as follows:

In 52 cases, no disease or injury was found and the patients were all returned to duty.

In 162 cases, a little over half of the total number, acute trauma (sprains, strains, contusions, fractures) was responsible for the symptoms. In this group, five patients with fractures of the spine and three with severe sprains were sent to general hospitals. Another patient with a severe strain was separated from service on CDD. The remainder, 95 percent of the total number in this group, were returned directly to duty. As these figures show, the soldier with an acute injury of the spine was in the highest degree rehabilitable. The man with a sprained or contused back, after a week or two of rest on a firm bed, supplemented by heat and a little massage, could also almost invariably be sent back to duty.

In 35 cases (11 percent of the total number), the patients were adjudged psychoneurotic; 28 were discharged on CDD and the other seven were returned to duty.

In 25 cases (9.8 percent), such conditions as arthritis and myofascitis were found; 18 of the men in this group were returned to duty, three were transferred to general hospitals, and four were separated on CDD.

In 21 cases (6.3 percent), the patients had such congenital deformities or variations of the spine as scoliosis, kyphosis, and spondylolisthesis. In this group, 10 men were returned to duty, including three of the four with spondylolisthesis, three were transferred to general hospitals, and eight were separated on CDD.

In 17 cases (5.3 percent), herniated nucleus pulposus was responsible for the syndrome. In this group, three patients became asymptomatic and were returned to duty, 13 were transferred to general hospitals, and one was separated on CDD.

Of the remaining patients, three with vertebral epiphysitis were all returned to duty, and one patient with tuberculosis of the spine was transferred to the Veterans' Administration.

In summary, of the 320 patients in this series, 248 were returned to duty (77.5 percent); 28 were transferred to general hospitals (8.7 percent), and 44 (13.7 percent) were separated from service on CDD. The subsequent fate of these patients is not known, but the immediate results, particularly the high proportion of men returned to duty, reflected their very creditable management at the Fort Jackson Station Hospital.

Lawson General Hospital

An analysis of 310 patients with low back pain observed at Lawson General Hospital during 1942 and 1943, by Maj. Dudley W. Smith, MC (*17*), furnishes some interesting contrasts to the analysis of 320 patients at the Fort Jackson Station Hospital. These admissions occurred in 6,103 admissions, which makes the apparent incidence of these complaints 7½ times greater than the incidence of the same conditions at the Fort Jackson Station Hospital. On the other hand, the population of a general hospital and that of a station hospital near troops in training are scarcely comparable.

Of these 310 cases, 148 (47.7 percent) were associated with sciatica.

The figures, again, are misleading unless it is recollected that this hospital also served as a neurosurgical center.

Of the 162 patients without sciatic radiation of their pain, 27 (8.8 percent) were classified as having functional or neuropsychiatric complaints. Of the remaining 135, 61 (45 percent) had chronic sprains; 17 (13 percent) had spondylolisthesis; 39 (29 percent) had arthritis of the hypertrophic or Marie-Strümpel type; and 15 (11 percent) had vertebral epiphysitis. Of the three remaining patients, two had scoliosis and one had tuberculosis of the spine.

In the Fort Jackson series, 77.5 percent of the patients were returned to duty. In the Lawson General Hospital series, the figures were the exact reverse: Of the 135 patients without sciatica, 106 (78.8 percent) were discharged on CDD. The situation suggests that many soldiers with actual physical findings and perhaps slight roentgenologic evidence of trouble were often inadequate personalities, with little desire for the rigors of an army camp. It is certainly hard to explain on any physical basis why an acute sprain or strain of the back should respond so rapidly to treatment while rehabilitation of a patient with a chronic sprain who had reached a general hospital should be a miserable failure.

There were 21 neuropsychiatric cases (8.8 percent) at Lawson General Hospital, against 35 (10.9 percent) at Fort Jackson Station Hospital. Of the 310 patients at Lawson General Hospital, including the 148 with sciatica, only 89 (29 percent) were sufficiently rehabilitated to return to duty. About a quarter of them were assigned to limited service, and grave doubts were felt that all of them would remain in that status.

Of the remainder, 221 (71.3 percent of the total) were discharged. Those sent to general hospitals would perhaps be rehabilitated, but were more likely to swell the number separated from service there on CDD.[2]

[2] Although no similar study seems to have been made in the Zone of Interior, an instructive study on low back pain carried out in the Persian Gulf Command is worth citing in this connection (*18*):

For the 20-month period ending on 31 October 1944, 466 patients, including troops of all branches of service, were hospitalized for some type of low back complaint. Some men had as many as six admissions for this cause. Over this period, the total troop strength in the area ranged from 12,868 in February 1943 to 29,589 in November of that year. Among the 466 patients were 138 truck drivers, 94 of them in the Quartermaster Corps (of a total of 104 Quartermaster Corps personnel in the hospitalized troops).

Investigation of the difficulties of these 138 men revealed the following etiologic factors:

1. Rough roads, particularly in the early months of the operation of the command, when from 8 to 12 hours were required to negotiate an average run of 150 miles.

2. Hard, uncomfortable seats, especially in two particular types of trucks, which caused every bump to vibrate through the driver's body.

3. Lack of supporting drivers' belts, which were not included in the table of equipment.

4. Long hours of driving, with insufficient rest periods, during peak tonnage months.

5. Continued use of army cots, which developed sags and did not afford proper relaxation for tired back muscles.

6. Failure of the drivers to apply for massage and heat therapy after long runs.

7. Failure of the drivers to report their symptoms until they had become severe, or very severe.

Accidents were more frequent in the early months of command operation, and there were, therefore, more specific injuries. Treatment often required long periods of hospitalization and much loss of time. Of the affected patients, 100 were transferred from field or station hospitals to general hospitals serving the command, and 20 were evacuated to the Zone of Interior for further observation and treatment.

Attention to certain simple measures would have greatly reduced the noneffective rate in this command in the low back syndrome, in which there seemed no doubt of the genuineness of the complaints.

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Part VIII

AMPUTATIONS

CHAPTER XXIX

Amputations: Historical Note

Leonard T. Peterson, M.D.

GENERAL CONSIDERATIONS

When the United States entered World War I in April 1917,[1] the almost 3-year wartime experience of the participating European nations, which covered almost 300,000 amputations, indicated the potential magnitude of the problem (*1, 2*). The gains brought about by improved surgical techniques had been counterbalanced largely by the general use of high explosive missiles and the prevalence of gas gangrene. At that, the number of amputations in World War I (as later in World War II) in U.S. troops was smaller, both absolutely and proportionately, than the number recorded in "The Medical and Surgical History of the War of the Rebellion" (*3*). In that war, about 3 million troops were mobilized, and there were 20,993 major amputations in the Union Army (8,518 of the upper extremity and 12,475 of the lower extremity) and an estimated 25,000 in the Confederate Army (*4*).

During United States participation in World War I, 4,403 amputees were evacuated from overseas to the Zone of Interior, with their injuries distributed as follows (*2*):

Twenty-three hundred forty-six amputations of the upper extremity, including 18 bilateral amputations, four of which were partial.

Two thousand thirty-two amputations of the lower extremity, including 42 bilateral amputations, three of which were partial.

Twenty-five amputations of an upper and a lower extremity in the same patient, in 14 of which, most of them involving the hand, the loss was partial.

The majority of amputations overseas were performed for trauma in forward hospitals. The majority performed for sepsis were performed in base hospitals to the rear. Consultation was required before any amputation in an overseas hospital.

In Circular No. 46, Office of the Chief Surgeon, American Expeditionary Forces, issued in France on 16 August 1918, it was directed that all

[1] The orthopedic sections of the official history of the U.S. Army Medical Department in World War I were prepared by Col. Elliott G. Brackett, MRC, who served as Chief of the Division of Orthopedic Surgery in the Surgeon General's Office during the war. The material is derived from reports made by 18 orthopedic surgeons, one of whom, Maj. (later Maj. Gen.) Norman T. Kirk, MC, was to serve as Surgeon General of the Army during World War II. Unless otherwise indicated, all the data in this chapter have been obtained from the World War I official history (*1, 2, 5*).

amputees should be assigned as soon as possible to the orthopedic service for whatever special treatment they might need (*6*). A casualty with a guillotine (open circular) [2] amputation and no other injuries could usually be moved without risk in a week. Within another 3 or 4 weeks, he could get about on a temporary prosthesis, without crutches. It was highly desirable that the transfer to the orthopedic service be made promptly, so that the temporary artificial limb could be fitted under the most favorable circumstances, before flexion deformities developed.

CLINICAL POLICIES OVERSEAS

In World War I, as in all wars, the technique of amputations in forward hospitals was necessarily based upon the subordination of military surgery to military logistics: [3]

1. In times of quiet or relative quiet, such as prevailed on the Western Front in the early months of 1918, amputation was usually performed at the level of the wound or immediately above it, with careful excision of all damaged or devitalized tissue. Flaps were formed from the sound tissues, and as much stump length as possible was preserved. If the timelag since injury was brief and the soft tissue damage well localized, the wound was occasionally closed primarily.

2. During periods of heavy combat activity, as from September 1918 to the armistice in November, the influx of casualties was enormous, demands for beds were in excess of the supply, and all hospital facilities were strained to the utmost. Surgical procedures had to be geared to the prompt evacuation of casualties to make room for more casualties. Moreover, because of the difficulties of evacuating wounded from the battlefield under heavy fire, the timelag between injury and hospitalization was usually much greater than in quiet periods, and as a result, wounds were often frankly infected before they came under treatment.

In these circumstances, while prompt evacuation was still necessary for logistic reasons, it was attended with greater risk of serious infection, particularly of anaerobic infection. If the stump had been even partially sutured, or if the flap technique had been used, even without closure of the stump, this type of infection could develop during transportation and could assume fatal proportions before the patient reached a hospital in which treatment could be instituted.

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[2] This unfortunate and entirely incorrect nomenclature (which persisted to the end of World War II) has been maintained in this chapter, along with other nomenclature of World War I, for the sake of verisimilitude.—M. C.

[3] The names and places were different, and there had been clinical and technical advances since World War I, but at that, it is surprising how closely many of the problems of World War II duplicated those of World War I and how many of the orthopedic principles and practices of the earlier war were useful in the Second World War.

Indications

Most of the amputations performed overseas, as already mentioned, were for trauma or sepsis. In a considerable number of cases, the indication was chronic sepsis combined with some hopelessly mutilating injury. It was evident in many of these cases that, even if the infection could be controlled, a better functional result could be obtained by prompt amputation and the fitting of a prosthesis. It was, of course, understood that the possibility of saving any part of a hand justified a long uphill fight. When the foot or leg was concerned, the functional result secured with an artificial limb was often much better than if a badly damaged foot or ankle had been retained in the name of conservatism.

Techniques

The flap technique used during the first months of United States participation in World War I was soon, to meet the realities of military surgery, replaced by the misnamed "guillotine technique," which had been adopted by Allied surgeons earlier in the war (*1*). This operation, properly performed, took very little time; preserved the maximum length of the stump; provided wide drainage; and permitted safe evacuation at the end of 48 hours, or even earlier if military circumstances demanded it. If the amputation was done for infection in the knee joint or at the upper end of the tibia, disarticulation by the flapless technique was a useful procedure, which could be performed with much less surgical risk than amputation through the thigh. Disarticulation also opened up a smaller amount of fresh tissue to the risk of infection and was not followed by troublesome retraction of the soft parts. Later, when the infection had been controlled, reamputation to "regularize" the stump could be performed under ideal conditions.

The disadvantage of open circular amputation, that it required a protracted period of treatment and usually a secondary reconstructive operation before a prosthesis could be fitted, was more than compensated for, in the opinion of most World War I surgeons, by its safety and its suitability to military conditions. Any reproaches directed against the operation should not have been charged against the technique but against the surgeons who performed it as a true guillotine (that is, meat-cleaver) procedure, without allowance for retraction of the structures. This error produced a stump with a conical surface, with protruding bone representing the apex and skin margins representing the base, and resulted in an unnecessary sacrifice of limb length when the stump was revised.

The chief objective of overseas management was to prepare the patient for evacuation to the United States. At no time in World War I was it the policy to undertake reconstructive surgery overseas unless return to duty could thus be achieved; that was neither probable nor possible

in any major amputation. Evacuation, however, was an uncertain procedure, especially for litter patients. Delays were numerous, and frequently several times as many patients were waiting transportation as could be accommodated in available convoys. In certain selected cases, the delay was utilized, therefore, to perform secondary reconstructive operations, chiefly in an effort to shorten the period of recovery or to render the long sea trip easier and safer than it would have been otherwise.

So far as is known, cinematization was attempted in only five cases in World War I, in two of which it was done overseas (*2*). In only one of the five operations was the functional result an improvement over results obtained by standard techniques, and in two cases, the failure was so complete that the tunnels had to be excised.

COMPLICATIONS

Among the complications of amputation encountered in World War I overseas, in the United States, or in both areas were the following (*2*):

1. *Secondary hemorrhage.* This was not a frequent complication of amputation nor a frequent indication for it. Hemorrhage that occurred 24 to 48 hours after operation usually resulted from improperly placed or insecurely tied sutures. Bleeding that occurred later was usually the result of sepsis.

2. *Infection.* This was an extremely frequent complication in both acute and latent forms. Many stumps resulting from modified amputations with irregular skin flaps showed a circular or irregular granulating area at the end of the stump, with partial marginal epithelization. Such areas looked unhealthy, and cultures from them almost invariably were positive for *Staphylococcus*, *Streptococcus*, or, occasionally, *Corynebacterium diphtheriae*.

In nearly every instance of soft-tissue infection, the bone was involved, and after the acute process had been controlled, a focus of chronic osteomyelitis, characterized by multiple sinuses, remained in the terminal portion. As long as the sinuses remained open, wound healing was reasonably satisfactory. Later, when only a central ulcerated area remained and the sinuses began to close, purulent exudate often would back up and abscesses would form. Excision of the terminal portion of the bone was indicated, or, if sequestration had occurred, excision of the sequestrum.

3. *Sequestration.* The most common type of sequestrum was a ring-shaped fragment, usually about 1.5 centimeters thick, which could be palpated if it was not visible. In some stumps it was almost encapsulated by new bone formation, which usually contained a small sinus.

4. *Other bony complications.* Excessive bone production at the end of the stump was frequent in open circular amputations. It was most often observed on the inner aspect of the femur, where it was frequently associated with osteophytes, which were sometimes so painful their surgical removal was necessary.

Interosseous bony union (cross union) occurred in both the upper and the lower extremity. In the forearm, the connecting bony overgrowth occasionally was removed when the stump was long enough for pronation and supination. In the leg, the condition was not regarded as harmful unless terminal sharp exostoses had developed.

Displacement of the patella occurred after some Gritti-Stockes amputations and displacement of a portion of the os calcis occurred after some Pirogoff's amputations. Additional surgery almost invariably was necessary when these techniques were used

Inequality in the lengths of the bones of the forearm and the leg occasionally required correction after amputation. In the leg, the prosthetic requirement that the fibula be about 2 centimeters shorter than the tibia had usually been met when the stump was revised.

5. *Soft-tissue complications.* Edema of the soft parts adjacent to the wound was the rule in most infections. Its extent depended upon the degree and character of the infection, as well as upon the site of amputation. It was more notable and more persistent in amputations below the middle third of the leg and the lower third of the forearm.

Soft-tissue retraction did not occur in a properly performed open circular amputation. It was the result of retraction of severed muscles, and it could be prevented or, if it had occurred, it could be corrected, by the efficient use of adhesive traction. Simple traction with pulley and weight was best for hospitalized patients, but fixed elastic traction with the Thomas splint was required for transportation.

Once traction was instituted, healing was usually rapid. With the flapless type of amputation, the end result was a thin, round scar, with or without sinuses, depending upon the presence and degree of bone infection. In short-flap amputation, the result was often a linear scar, which sometimes permitted fitting of a prosthesis without additional surgery. Most open amputations, however, even when correctly treated by traction, required secondary surgery to eliminate the scar and, in some cases, the infected tip of bone.

Stumps with redundant soft tissue were seldom seen. They were usually associated with late necrosis or extensive bony comminution, without corresponding damage to the soft parts. The excess was never removed until the need for the tissue had been fully considered, as well as the possibility of utilizing it by osteoplastic techniques to increase the length of the stump.

6. *Joint complications.* Contractures (deformities) with limitation of movement of the stump were preventable complications which could have serious consequences. They were the result of fixation of the stump for a considerable period of time in an undesirable position and they were most apt to develop in short stumps. The patient with a sensitive stump invariably tried to get it into a position of muscular relaxation and then avoided moving it. If he were permitted to do this, the result was shortening of the muscles, contraction of the capsule, and limitation of movement. The complication frequently occurred at the hip or the knee and was particularly likely to develop when the "baneful" practice of propping the stump in flexion on a pillow was permitted (*2*).

Other contractures included incomplete extension of the knee after amputation of the lower leg, flexion of the hip after amputation through the thigh, flexion of the elbow and limited rotary movements of the forearm after amputation through the forearm, and adduction of the shoulder after amputation of the arm. All these impaired movements were precisely those most essential to obtain optimum function with prosthetic devices.

These deformities were usually preventable. When splinting was employed after amputation, it was necessary only to fix the joint in the most desirable position and require the patient to move it through the normal range of motion several times a day. Continuous traction, in addition to preventing retraction of the tissues, was also an excellent method of preventing contractures. In amputations of the arm, the splint was usually so applied as to hold the shoulder abducted. In amputations of the leg and thigh, the knee and hip were held in extension.

When joint deformities had developed, they were managed by massage and exercise and, when practical, by the application of provisional prostheses; the active voluntary movements which these prostheses stimulated proved the most valuable single measure in counteracting contractures. When, for any reason, a prosthesis could not be applied, the best treatment was continuous extension or corrective splinting.

7. *Residual complications.* The majority of painful stumps resulted from infection or its sequelae or from circulatory disturbances. Neural complications in the form of painful neuromas were a late development.

SURGICAL MANAGEMENT IN THE UNITED STATES

Early in 1918, when the number of amputees returning from overseas was small, most stumps were healed when the patients were received and many could be fitted at once with temporary prostheses (*2*). Later, when the number of wounded increased and they were received earlier for logistic reasons, most stumps were only partly healed. In most instances, the primary operations had been performed in accordance with official policies for sites and techniques of amputation.

The chief therapeutic problem was the large number of open wounds (*2*). Little difficulty was experienced in patients who had been treated successfully by either primary or delayed closure. Because of the military circumstances, however, the number of these amputees was small. Closure had been attempted in not more than 10 to 12 percent of the patients received, and the number of successes was far smaller.

The first several hundred patients received in the United States with unhealed stumps were handled with extreme conservatism, in the hope that by the use of skin traction and other nonsurgical measures, healing would occur within a reasonable time and no further surgery would be necessary in most cases. A brief experience indicated the futility of this hope. It proved impossible to obtain complete healing in open circular stumps by these methods, even when a very long time was allowed, and the resulting scar was not sufficiently tolerant of trauma to permit the application of a prosthesis. It was also found that many stumps required reamputation at a higher level, and that a limited amount of bone could be removed without damaging the stump functionally. In the light of this experience, it became the practice to employ surgical techniques designed to obtain a firm closure with freely movable skin before cicatrization was advanced.

Surgical treatment in the United States in World War I was based on three classifications of the stump, as follows:

1. *The unhealed stump.* Bone length required careful consideration in all of these cases, and there were instances in which it was necessary to sacrifice ideal soft-tissue conditions to preserve it. In the majority of guillotine amputations, however, little was lost in ultimate function by removal of limited amounts of bone, and much was probably gained by eradication of pathologic tissue. The actual size of the unhealed area could be ignored in this group of cases, but the suitability of the stump for the fitting of a prosthesis always had to be borne in mind.

2. *The stump that was already too short.* In this group of cases, there could be no question of additional sacrifice of bone. It was imperative that 6 to 8 months should have elapsed since wounding and that, in addition to other preoperative requirements, the wound should be completely cicatrized or that the unhealed area should be very

small and "practically sterile." The objective of surgery in this group of cases was to remove intolerant scar and replace it by freely movable, healthy skin. Pedicle grafts were useful, particularly when the amputation had been at a critical level, but Thiersch's and Reverdin's grafts, while they hastened closure, did not produce scars firm enough to stand up under normal usage with a prosthesis.

3. *The stump that required reamputation.* In this group of cases, it was possible to disregard, to a considerable degree, the terminal aspect of the stump and to proceed with definitive surgery earlier than in either of the other groups because there was no doubt of the need for sacrifice of additional bone and soft tissue. It was necessary, however, to adhere strictly to established criteria concerning the patient's general condition, his ability to tolerate major surgery, and the disappearance of infection and edema in the soft parts.

The required treatment in this group of stumps was always formal reamputation. Reamputation was practically equivalent to primary amputation under ideal conditions, and it necessarily demanded careful consideration of the site in relation to ultimate function. The value of a stump in terms of function could be correctly estimated only in relation to the prosthesis.

In spite of the almost universal presence of infection in stumps in which secondary surgery was to be done, conditions for operation were highly favorable as contrasted with those existing at the time of primary amputation overseas. Then, the principal consideration was eradication of the potentially life-endangering pathologic process, with minimum sacrifice of limb length. Under the comparatively favorable conditions existing at the time of secondary surgery, it was possible to give full consideration to the prosthetic and functional requirements of the stump.

The septic stumps that constituted such an important part of orthopedic surgery in the Zone of Interior in World War I (in contrast to their small numbers in World War II) usually represented only the continuation of a process begun overseas, a process for which, in many instances, the amputation itself had been performed. Equally important was the endless trouble encountered when partial closure of such a stump had been attempted or when flaps had been formed and tended to fall together. In many of these cases, residual abscesses developed and required drainage.

In some cases, the infection extended to the adjacent joints and produced a septic arthritis. In below-knee amputations, with secondary infection and suppurative arthritis of the knee joint, reamputation above the knee was resorted to relatively promptly.

TIMING OF SECONDARY SURGERY

Until the stump was considered surgically sound, nothing was gained by hastening secondary surgery and applying a temporary prothesis (*2*). Only a brief experience was needed to show the folly of attempting plastic closure of stumps or of reamputations adjacent to unhealed areas until sufficient time had elapsed from date of the original injury. Early closure of infected open circular stumps resulted in a high percentage of failures, for two reasons:

1. The frequently poor *general condition of the patient following* trauma and his subsequent surgical and postoperative ordeal.

2. Absorption of toxins from latent infections of the stump. The infectious process was often found to be present not only in the terminal granulating areas of the stump but also, for a considerable distance, in the lymphatic channels proximal to the unhealed areas.

Attempts to establish standards of timing by cultural techniques proved unreliable, if only for the reason just mentioned, that they provided no precise information as to the extent of latent infection farther up the limb. It was far better to rely upon clinical observations, particularly the appearance of the stump and the general condition of the patient, before undertaking surgery. As long as the stump remained swollen, boggy, and edematous, it could be assumed that latent infection was still present and that attempts at plastic closure would fail. The disappearance of edema usually coincided with a gradual improvement in the general condition of the patient. Final closure was, therefore, deferred until:

1. The skin and subcutaneous tissues were soft, dry, wrinkled, freely movable, and without any trace of edema.

2. All sinuses leading to bone or to foreign bodies had been eliminated.

3. Cultures from unhealed areas showed no streptococci and the field count was reasonably low (less than five to a field) for other less virulent pyogenic organisms.

IMMEDIATE MEASURES

The following general measures were employed when amputees were received in general hospitals in the United States:

1. All possible steps were taken to improve their general condition.

2. The importance of bed rest, usually in the form of actual recumbency, was emphasized in the treatment of large infected wounds. It was noted repeatedly that wounds that had remained practically stationary while patients were ambulatory promptly improved when recumbency was enforced.

3. The Carrel-Dakin treatment was used on all infected stumps as long as the unhealed area was large, concave, and discharging a profuse purulent exudate. Dichloramine-T was substituted when the wound decreased in size and granulations appeared healthy and reasonably clean.

4. Massage of the terminal area was useful in several ways. In healed stumps, with small scarred areas of soft tissue adherent to the bone, it aided in softening the scar tissue, improved the circulation, and thus increased resistance to trauma.[4] In unhealed stumps, massage of the skin adjacent to the area of scarring decreased edema, generally improved the

[4] This was a concept not accepted or implemented in World War II.

circulation, and made the skin looser and more redundant before plastic surgery was undertaken.

5. Skin traction was routine in both recumbent and ambulatory patients. In the former group, direct extension was employed by means of adhesive strapping, pulleys, and weights (a technique that was accurately described (*3*) in the history of the Civil War).

Traction was, of course, most effective when it was applied immediately after amputation because, at that time, it rapidly reduced the extent of the open area. If it had not been applied early and if the skin had been allowed to retract and to become adherent, it was much less effective and much more time was necessary to prepare the stump for revision.

In a few short stumps, in which there was wide retraction of the skin, it was found best to dissect the skin free and then apply traction before attempting final plastic closure. The favorable influence of traction in the prevention of joint deformities was repeatedly observed.

POSTOPERATIVE MANAGEMENT

When a wound had been closed under even moderate tension, provision for traction was made in the operating room. In other cases, unless tension was extreme, weights were often not applied until the following day. Traction was found of definite value in the prevention of postoperative hemorrhage, as well as in its contribution to the patient's comfort.

Drains were usually removed in 24 hours. If secondary hemorrhage occurred, with ballooning of the flaps, the best plan was to remove the sutures, clean out the clots, and reapply traction. Hemorrhage, as already noted, was most likely to occur when ligation of the blood supply had been inadequate.

Each time the wound was dressed, the stump was moved through the maximum range of motion.

As soon as the patient could be out of bed, he was fitted with a provisional prosthesis. The stump was kept bandaged whenever the prothesis was not worn. Massage and baking were carried out daily, to stimulate the circulation and prevent edema.

PROSTHESES

The Situation in April 1917

When the United States entered World War I, a thriving artificial limb industry already existed (*2*). The large number of amputees in the Civil War (*3*) and the subsequent enormous increments from industrial accidents had greatly stimulated work in this field. Moreover, the industry

was well distributed geographically, one or more firms being located in each of the larger cities. The output of some of these firms was small and their shop facilities were far from modern, but since the outbreak of the war in 1914, a considerable number of the larger firms had greatly increased their prewar activities by supplying artificial limbs to the Allies.

Initial Activities in the Surgeon General's Office

The Surgeon General recognized from the first the importance of adequate provision for study of the design and construction of prostheses and for proper testing of the many new appliances and devices constantly being presented to his office. He was aware that the problem had already become serious abroad, where the supply of prostheses was far short of the demand and where many of the limbs used were less efficient than it seemed reasonable to expect them to be.

In August 1917, The Surgeon General assigned to orthopedic surgeons the care of "cases requiring surgical appliances, including artificial limbs" (*5*). A member of the Division of Orthopedic Surgery in his office was assigned to this work, and the Division of Physical Reconstruction turned over to him all questions of equipment and supply.

A considerable literature on this subject had appeared since the outbreak of the war, and it seemed desirable to study it carefully and evaluate the previous experience before making any radical changes in either clinical or prosthetic policies. A visit to the military orthopedic hospital in Toronto, Canada, provided much useful information. At the suggestion of the Council of National Defense, the manufacturers of artificial limbs formed the Association of Artificial Limb Makers of the United States in October 1917, and many conferences were held with its representatives at their headquarters in Washington (*2*, *5*). A number of these manufacturers had visited Europe earlier in the war and several of them had established factories abroad. They were, therefore, in a position to render a great deal of assistance to U.S. Army orthopedic personnel.

A questionnaire sent out by The Surgeon General indicated that the artificial limb industry as a whole, with existing equipment, could produce a thousand limbs a month, over and above the number required for civilian needs. Examination of the products of various large manufacturers showed that, while their prostheses differed in minor details, they were similar in design in all essential points, very substantial in construction, and generally excellent in workmanship.

Standardization, while a proper subject for attention during times of peace, must be based on extensive studies, and it was not considered a suitable undertaking in time of war, particularly since the limbs produced by commercial manufacturers were so satisfactory. It seemed

wiser, therefore, to permit these concerns to continue to produce their own models rather than to select any single model as the standard for them all. Since all manufacturers who desired to supply limbs to the Government would be bonded, incompetents would be eliminated in short order.

The Surgeon General also authorized the establishment of an artificial limb laboratory. The equipment, which at first was deliberately kept simple, was installed at the Army Medical School, Washington, D.C., in January 1918, and a certain amount of prosthetic work was carried out there in the orthopedic section shops. In March 1918, the laboratory was moved to Walter Reed General Hospital, Washington, D. C., to secure better coordination between the experimental and clinical phases of the work.

In spite of the favorable situation in which the United States found itself in 1917 in respect to the artificial limb industry, there were two major problems. One was difficulty in securing supplies. The second, and more serious, concerned personnel. Skilled workmen in this field were being lost to the draft or by transfer to munitions work, and replacing them was much more difficult than had been anticipated. The solution of the personnel problem was the training of new men in the various details of limb construction and fitting.

Issue of Artificial Limbs

Up to November 1917, artificial limbs were issued by the U.S. Army Medical Department by authority of the War Department. On 16 November, Congress provided for their issue to discharged military personnel through the Bureau of War Risk Insurance, which meant transfer of authority to the Treasury Department. Thus, at an important stage of his medical treatment, the amputee passed from the control of one branch of the Government, the Army Medical Department, to another, which was not medical.

Personnel of the Medical Corps realized that the highest degree of functional use of an artificial limb could be assured only through a planned organization which took into account every phase of management, including (1) the amputation itself, (2) care of the stump, (3) fitting and provision of the prosthesis, (4) general functional training, and (5) special vocational training. During these stages, the amputee passed, successively, under the care of the surgeon, the artificial limb-maker, and the educational officer.

To retain the amputee in the hospital during the long period necessary for the stump to attain its final form and be in proper condition for the fitting of a permanent artificial limb was obviously inadvisable from the standpoint of hospital utilization and equally inadvisable for the patient. Yet, it was essential to provide for his proper training in the use of

the prosthesis he would wear permanently. This training, in fact, was one of the most important phases of his care. The functional value of the first prosthesis could hardly be overestimated.

Provisional Prostheses

The most satisfactory solution of the problem presented by the Congressional action of November 1917 was to provide temporary prostheses, of regular design but constructed with the objective of meeting the requirements of the wearer only during the first 12 months of his life as an amputee. An artificial limb of this kind was easy to provide on a readymade basis. Fiber could be used in place of wood, and a wood socket could be adapted very satisfactorily to thigh amputations. In below-knee amputations, the fiber socket could be constructed to hold a plaster-of-paris socket. An artificial arm was even easier to construct than an artificial leg.

The plan just outlined had many advantages. Since all parts of the manufacturing process could be carried out at established plants, a minimum demand was made upon the industry. Production in any needed quantity was possible, so that a maximum number of amputees could be cared for. Sufficient parts could be carried in stock to fit amputees of various heights and sizes. The time required for fitting the readymade prosthesis was much less than that required for one that was specially constructed.

Early in World War I, members of the Belgian Army Medical Corps had demonstrated the beneficial effects of early weight-bearing in lower extremity amputations (*1*). It improved the circulation and thus promoted wound healing. It hastened stump shrinkage and prevented muscle atrophy and joint contractures; in these respects, it was far more useful than any form of physical therapy. If a terminal localized osteomyelitis was present, early weight-bearing favored the separation and spontaneous discharge of sequestra. In healed stumps, it expedited the fitting of the permanent artificial limb and thus shortened the period of convalescence. Finally, it had an important psychological effect on the amputee's morale.[5]

The principle of early prosthetic fitting was utilized as far as possible in U.S. amputees overseas. Appliances of suitable design and sufficient simplicity were developed, and arrangements for their manufacture were made with the American National Red Cross in France. This plan was applicable to not more than 20 percent of all amputations of the lower extremity, but when it was practical, the results were generally excellent.

The sockets for temporary prostheses were usually made of plaster of paris, with a framework of wood or metal. In one center, a papier-

[5] It is interesting to note that the principle of early weight-bearing after amputation is now (1967) being vigorously revived, with excellent results.

mâché socket was found very satisfactory. The limb was fixed to the socket by a few turns of plaster bandage. The same bearing points were used as for permanent artificial limbs.

An ideal provisional appliance possessed, in the main, the mechanical features of a permanent appliance. A prosthesis which simply shrunk the soft tissues and did not develop the tolerance of bearing points and surfaces which would be called upon to function when a permanent appliance was provided was not considered efficient.

Provisional appliances had many advantages. With them, it was possible to get patients out of bed and walking without other support very soon after amputation, often within 2 to 3 weeks if the stump was clean and closed. If the stump was open, it was necessary to wait longer.

Provisional prostheses were more versatile as regards refitting than were peg legs and other crude appliances, which amputees found offensive for esthetic even more than for functional reasons.

When provisional prostheses were provided, it was possible to coordinate the surgical, prosthetic, and physiotherapeutic phases of management, and to carry out the reeducational program that was an essential part of it, without holding the amputee unduly long in the hospital. Surgical defects of stumps usually became apparent while the patient was still under Army control and they could be corrected at once. Finally, the amputee had an opportunity to learn something about appliances and could make a more intelligent choice of the permanent prosthesis he would select for himself when he passed out of Army medical control.[6]

AMPUTATION CENTERS

Practical considerations, plus the experience of other countries, had indicated, by 1917, the desirability of segregating amputees, as far as possible, in single centers reserved exclusively for them (*2, 5*). The fitting of prostheses was greatly facilitated by this plan, and training in all its stages, as well as studies on various problems of amputation, could be carried out under ideal conditions.

The extent of the United States made a single amputation center completely impractical. Arrangements were therefore made for a principal center (Walter Reed General Hospital) near ports of debarkation, with subcenters in other parts of the country. Early in 1919, General Hospital No. 3, Colonia, N.J., was designated as distributing center for all amputees arriving at the port of New York and Walter Reed General Hos-

[6] The fiber prosthesis used in World War I was manufactured by the Minneapolis Artificial Limb Co., Minneapolis, Minn. It was used continuously after the war at Walter Reed General Hospital and at certain times, it was also used at Letterman General Hospital. In January 1942, Col. Norman T. Kirk, MC, recommended that it be used in World War II as the best and cheapest prosthesis available (p.). The recommendation was accepted and the limb was standard throughout the war except at the McGuire General Hospital Amputation Center, Richmond, Va., the last center to be established, where aluminum prostheses were chiefly used.

pital as the center for all those arriving at Newport News, Va. Eventually, only the port of New York was used for this purpose.

The amputation center at Letterman General Hospital, San Francisco, Calif., was the smallest center in point of numbers. In the late spring of 1919, each of the other five centers then in operation was caring for between 600 and 700 patients.

The ward organization of large amputation centers had much to do with their success. Treatment could be carried out more readily, and discipline could be more readily enforced, when patients were divided according to stages of treatment into four groups; namely, (1) unhealed stumps (further subdivided into ambulatory and recumbent), (2) preoperative and postoperative, (3) prefitting and postfitting, and (4) training.

Medical personnel consisted of the chief of service, who also exercised supervision over the appliance shop; one or more assistants, depending upon the size of the center; one officer, or sometimes two, in charge of the appliance shop; and the usual ward officers. The assignment of an additional officer to the fitting wards as well as the shops improved both fitting and supervision.

An appliance shop for artificial limb fitting was installed at every center except that at Fort Snelling, Minn., where the close proximity of a manufacturer of provisional appliances made it simpler to have the fittings done at the factory.

It was found to be unnecessary as well as uneconomical to install expensive equipment in the appliance shops. Parts whose construction required unusual or elaborate machinery could readily be secured from commercial manufacturers. As a rule, the equipment provided was little more than what was needed in an orthopedic braceshop. Considerable floor space, however, was necessary to take care of large numbers of amputees without any waste of time.

EDUCATIONAL ACTIVITIES

Medical personnel.—A great deal of educational work was needed for all concerned with the amputation program as well as for amputees themselves. Orthopedic surgeons were still uncertain as to preferable sites of amputation. The circular amputation most suitable in military surgery required, if infection was to be avoided, a type of aftercare entirely different from that required by the amputation customary in civilian practice. Little attention had been paid in the past to systematic care of the stump. Not a great deal was known about prosthetic principles. The use of temporary prostheses with plaster-of-paris sockets as a means of instituting early weight-bearing was practically unknown in the United States in 1917.

Information on these points covered in articles on amputations and

prostheses was distributed in reprint and other forms to Army surgeons. Student officers were given didactic lectures and practical clinical demonstrations. Artificial limb makers were frequently called on to explain the design and construction of artificial limbs and the principles of fitting. Educational officers and reconstruction aides were given lectures, supplemented by moving pictures, covering details of the later phases of training. After the amputation center was established at Walter Reed General Hospital, medical officers were sent there for instruction in the care of the stump, the principles of surgery on the stump, the technique of construction of temporary peg legs, and general prosthetic principles.

Amputees.—The Division of Physical Reconstruction in the Surgeon General's Office was responsible for the educational phase of the amputation program in World War I. General educational work consisted of lectures and practical demonstrations in which civilian amputees who had acquired skills showed what was possible for handicapped men. Facts useful to amputees were formulated and issued in pamphlet form. Later, information was given concerning the details of procurement of permanent prostheses.

Results in training depended in no small degree on the attitude of the general public. The slight degree of incapacitation for most occupations caused by the loss of a leg, if a proper appliance was worn, was general knowledge. The possibilities of employment with the loss of an arm were not so generally known, and with only occasional exceptions, employers were prejudiced against hiring men with such a handicap for manual occupations. It was, therefore, imperative that the public be taught in what occupations and to what extent amputees could carry on productive labor. The success of this part of rehabilitation of amputees was made possible in large part through the generous assistance of many amputees throughout the country who had themselves obtained positions of competence.

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CHAPTER XXX

Administrative Considerations in the Amputation Program

Leonard T. Peterson, M.D.

Section I. Statistical Data

BASIC STATISTICS

Official statistics for World War II indicate that, between 1 January 1942 and 31 March 1946, 14,912 amputees were treated in amputation centers in the Zone of Interior.[1] These figures do not include data on amputees who died overseas or who for any other reason did not reach amputation centers in the United States. They also do not include non-disabling amputations of fingers or toes compatible with continued military service. They cover only major amputations, which were defined, for purposes of record, in the Surgeon General's Office as the loss of all digits in the upper extremity, the loss of any portion of the upper extremity above the level of the digits, or the loss of any portion of the lower extremity at or above the tarsometatarsal joint.

The 15,993 amputations performed on these 14,912 casualties were distributed as follows:

Thirteen thousand eight hundred forty-four amputations of single limbs (10,620 of the lower extremity, 3,224 of the upper extremity).

One thousand fifty-seven amputations of two extremities (870 of both lower extremities, 57 of both upper extremities, 130 of one upper and one lower extremity).

Nine amputations of three limbs (eight of both lower and one upper extremity, one of both upper and one lower extremity).

Two quadruple amputations.

In World War II, as these figures indicate (chart 3), the lower ex-

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[1] The card index files maintained at all amputation centers for all amputees were transferred to the Surgeon General's Office as each center closed and there became a part of the permanent files. The official statistics used in the chapters on amputations were obtained from them.

The difference between the figures just cited and those in table 14 is not a discrepancy. The former figures cover the period from 1 January 1942 to 31 March 1946 and the latter, the period from January 1943 to December 1945, when the largest number of amputations occurred.

tremity was involved in approximately eight of every 10 amputations observed in Zone of Interior Centers, most of them below the knee. In the upper extremity, the amputations were distributed about equally above and below the elbow.

The total census of all amputation centers for the period May 1944–March 1946 was as follows:

1944	*Number of amputations*
May	1,096
June	1,287
July	1,512
August	1,976
September	2,490
October	2,960
November	3,542
December	4,045
1945	
January	4,802
February	5,771
March	6,853
April	7,926
May	8,793
June	9,246
July	8,891
August	8,581
September	7,966
October	7,285
November	6,469
December	5,728
1946	
January	4,976
February	4,051
March	3,179

The data presented in tables 14–17 and charts 3–5 are self-explanatory. Certain aspects of the various statistics are discussed elsewhere in this chapter.

COMPARATIVE STATISTICS

Contrary to what might have been anticipated from the increases in effectiveness of weapons in World War II, the number of amputations in that war, both proportionately and absolutely, was smaller than in the Civil War, in which about 3 million troops were mobilized (*1*). In the Civil War, there were 20,993 major amputations in the Union Army (8,518 of the upper extremities, 12,475 of the lower extremities) and an estimated 25,000 in the Confederate Army (*2*). No triple or quadruple amputations resulted from battle injuries in World War I.

The annual report of the Surgery Division, Surgeon General's Office, for 1943–44 (*3*) contains an interesting analysis of amputations in World

CHART 3.—*Distribution of amputations in U.S. Army in World War II, by cumulative admissions and dispositions, May 1944–March 1946*

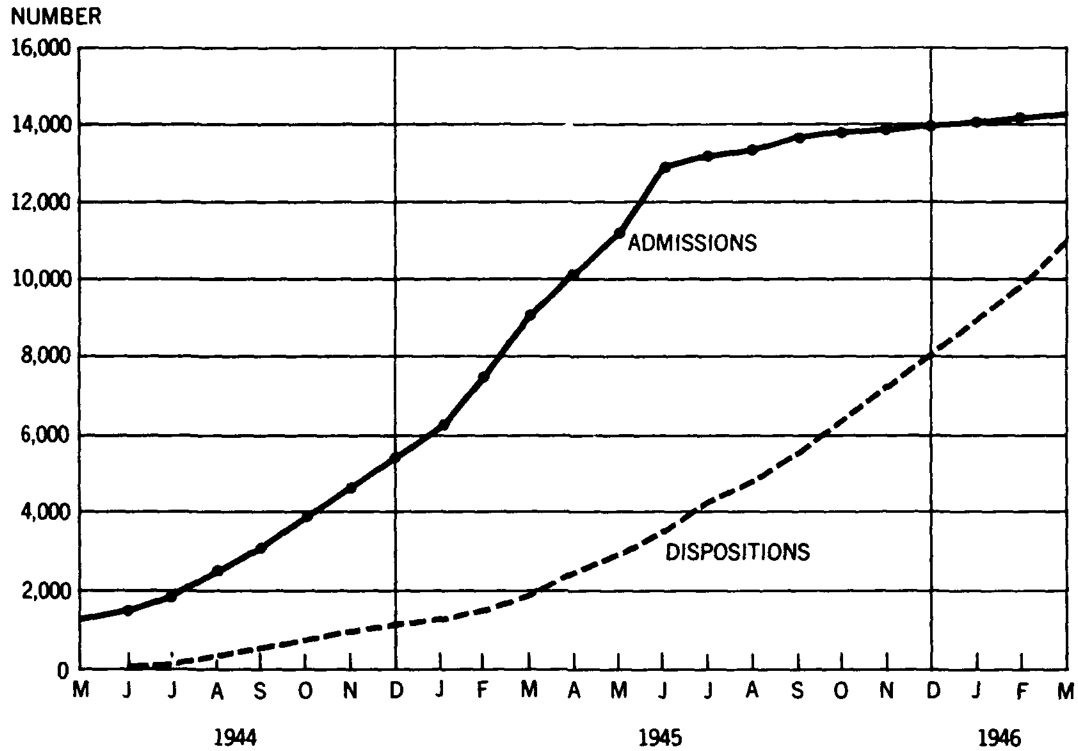

CHART 4.—*Distribution of amputations in U.S. Army in World War II, by location of amputation, December 1941–April 1946*

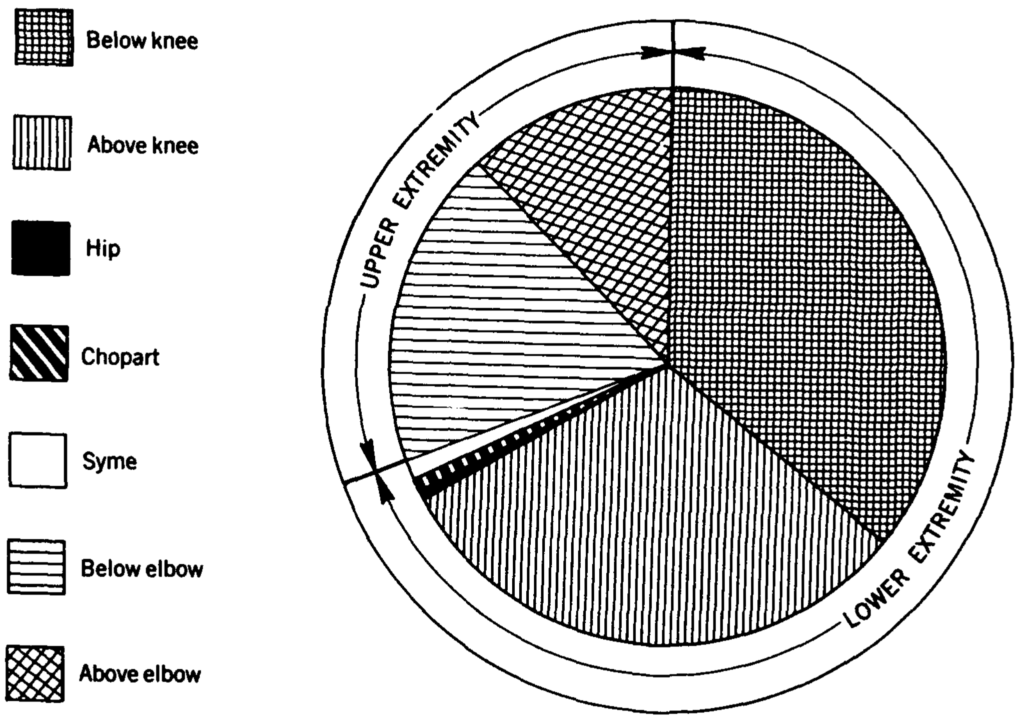

CHART 5.—*Total census of all amputation centers, May 1944–March 1946*

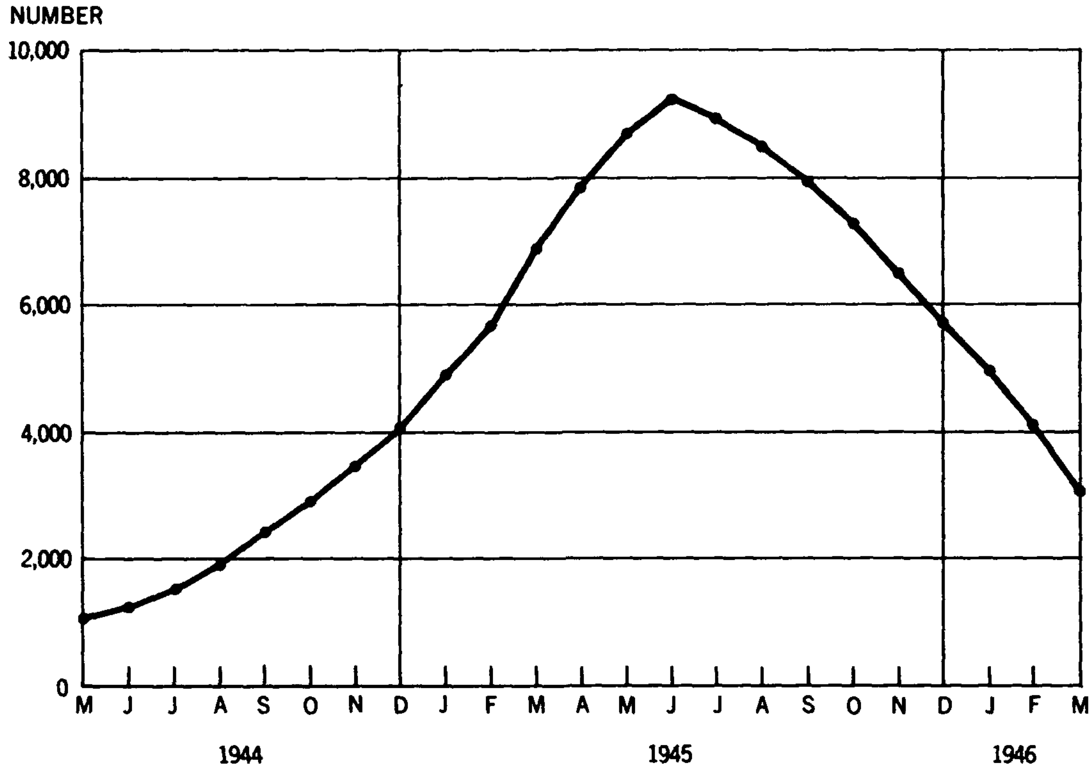

TABLE 14.—*Number of admissions*[1] *to U.S. Army amputation centers, January 1943–December 1945*

[Preliminary data based on reports from amputation centers]

Center	January 1943–April 1944		May 1944–December 1945		January 1943–December 1945	
	Number of amputees	Number of stumps	Number of amputees	Number of stumps	Number of amputees	Number of stumps
Bushnell General Hospital	203	217	2,043	2,160	2,246	2,377
England General Hospital		[2]	2,106	2,251	2,106	2,251
Lawson General Hospital	241	252	1,942	2,075	2,183	2,327
McCloskey General Hospital	271	284	2,339	2,476	2,610	2,760
McGuire General Hospital		[3]	735	780	735	780
Percy Jones General Hospital	367	382	2,494	2,681	2,861	3,063
Walter Reed General Hospital	588	624	1,825	1,963	2,413	2,587
Total	1,632	1,718	12,926	13,782	14,558	15,500

[1] Admissions for major amputations. Data for each center include cases transferred from another amputation center; total includes new cases only.

[2] England General Hospital was established in August 1944.

[3] McGuire General Hospital was established in March 1945.

Source: Medical Statistics Division, Surgeon General's Office, Department of the Army, 14 Oct. 1955.

War I compared with the figures for World War II from 1 January 1943 to 1 May 1944; the heaviest casualties in that war, it should be remembered, were still to come.

In World War I, 4,057,101 troops were mobilized, as compared with 11,367,989 in World War II.

In World War I, total casualties from missiles amounted to 147,651, and there were 2,687 amputations (including 52 double amputations) distributed regionally as follows:

Six hundred two amputations above the elbow, 22.40 percent.
Two hundred seventy-eight amputations below the elbow, 10.35 percent.
Twelve hundred eighty-two amputations above the knee, 47.71 percent.
Five hundred twenty-five amputations below the knee, 19.54 percent.

In addition, 1,509 casualties lost portions of the hand, and 292 lost portions of the foot.

In World War II, for the period studied (1 January 1943 to 1 May 1944), there had been 1,670 major amputations, with 1,759 stumps, 89 casualties having lost two limbs each. The regional distribution was as follows:

Two hundred fifteen amputations above the elbow, 12.22 percent.
Three hundred twenty-six amputations below the elbow, 18.53 percent.
Five hundred fifty amputations above the knee, 31.27 percent.
Six hundred twenty-seven amputations below the knee, 35.64 percent.

In addition, there had been 20 Syme and 13 Chopart amputations, and eight amputations at the hip joint.

TABLE 15.—*End-of-quarter census of amputees at U.S. Army amputation centers, 30 June 1944–31 March 1946*

[Preliminary data based on census reports from amputation centers]

Date	Bushnell General Hospital	England General Hospital	Lawson General Hospital	McCloskey General Hospital	McGuire General Hospital	Percy Jones General Hospital	Walter Reed General Hospital	All centers
1944								
30 June	147	([1])	212	171		308	452	1,290
30 September	229	38	674	317		640	592	2,490
31 December	423	619	842	770		877	514	4,045
1945								
31 March	1,107	1,217	1,085	1,263	([2])	1,279	902	6,853
30 June	1,498	1,595	1,328	1,569	636	1,592	1,028	9,246
30 September	1,200	1,486	1,121	1,242	688	1,367	862	7,966
31 December	792	1,121	788	854	544	897	732	5,728
1946								
31 March	402	588	546			855	788	3,179

[1] England General Hospital was established in August 1944.
[2] McGuire General Hospital was established in March 1945.

Source: Medical Statistics Division, Surgeon General's Office, Department of the Army, 14 Oct. 1955.

In World War I, as the figures cited show, amputations above the knee were considerably more numerous than those below the knee. The reverse was true in World War II, though the disparity was by no means as striking. The World War II figures probably reflect the greater therapeutic conservatism and improved surgical competence of that period. In World War II, one amputee in every 20 lost two extremities, but less than one in every 200 suffered a hip joint amputation. Amputation was more frequent distal to the elbow and knee than proximally, and the incidence of amputation in the lower extremity was more than twice that in the upper. Statistics based on maximum strength of the Army for given

TABLE 16.—*Peak end-of-month census of amputees in U.S. Army amputation centers, by center and date of peak load*

[Preliminary data based on census reports from amputation centers]

Center	Peak census	Date
Bushnell General Hospital	1,498	30 June 1945
England General Hospital	1,625	31 July 1945
Lawson General Hospital	1,328	30 June 1945
McCloskey General Hospital	1,617	31 May 1945
McGuire General Hospital	695	31 July 1945
Percy Jones General Hospital	1,592	30 June 1945
Walter Reed General Hospital	1,028	30 June 1945
All centers	9,246	30 June 1945

Source: Medical Statistics Division, Surgeon General's Office, Department of the Army, 14 Oct. 1955.

TABLE 17.—*Cumulative admissions and dispositions of amputees, May 1944–March 1946*

Date	Cumulative admissions	Cumulative dispositions
1944		
May	1,315	....
June	1,514	8
July	1,869	138
August	2,522	327
September	3,136	427
October	3,944	765
November	4,647	886
December	5,401	1,137
1945		
January	6,251	1,230
February	7,482	1,492
March	9,028	1,956
April	10,574	2,429
May	11,919	2,907
June	12,915	3,450
July	13,343	4,233
August	13,523	4,723
September	13,661	5,476
October	13,843	6,339
November	13,944	7,256
December	14,017	8,070
1946		
January	14,092	8,897
February	14,152	9,882
March	14,239	10,841

periods in World War I showed that only 2 percent of the troops sustained major amputations as compared with 5.3 percent in World War II, which probably reflects the more devastating properties of modern weapons, or perhaps the higher immediate mortality of World War I. Although the Syme technique was favored whenever possible, in the light of the Canadian experience with it (p. 973), few injuries requiring amputation were sustained low enough to permit it.

Comparative figures are not available for World War I, but in the period studied in World War II, 361 amputees were ready for fitting of their prostheses when they were received in the Zone of Interior (21.6 percent) and 1,309 required preliminary revision of the stump.

The World War II figures just analyzed included a few amputations for cold injury from the Aleutians; the Consultant in Orthopedic Surgery observed five such cases at McCloskey General Hospital, Temple, Tex., when he visited the amputation center there in December 1943. Here and at other hospitals, he was deeply impressed by the number of amputations from train and vehicular accidents, as well as from training accidents

in the United States. Hospitalized at this time at McCloskey General Hospital were seven hand amputees, two bilateral, who had sustained their injuries from grenades and mines during training in nearby camps.[2]

Section II. The Amputation Program

CONSULTANT PERSONNEL

When Col. Leonard T. Peterson, MC, was assigned to the Surgeon General's Office as Director of the Orthopedic Surgery Branch on 17 December 1943, when this branch was formally established, perhaps his most urgent duty was the supervision and coordination of all activities connected with amputations and prostheses (*6*). Amputation centers had been established on 6 March 1943 (*7*), but very few medical officers had had much experience in this special field before their military service. It was Colonel Peterson's responsibility to recommend the assignment of key personnel to these centers; to act as liaison officer between the centers and the Surgeon General's Office; and to settle problems involved in the care of amputees as they arose in connection with administration, personnel, equipment, surgical technique, and the fitting of prostheses and training in their use. He received assistance as necessary from other divisions of the Surgeon General's Office; members of the Subcommittee on Orthopedic Surgery, Committee on Surgery, Division of Medical Sciences, NRC (National Research Council); representatives of the prosthetic industry; and the civilian Consultants in Orthopedic Surgery to The Surgeon General, who included:

Dr. LeRoy C. Abbott, Professor of Orthopedic Surgery, University of California School of Medicine, San Francisco, Calif.

Dr. George E. Bennett, Professor of Orthopedic Surgery, Johns Hopkins University School of Medicine, Baltimore, Md.

Dr. Harold R. Conn, Surgical Director, Goodyear Tire and Rubber Co., Akron, Ohio.

Dr. J. Albert Key, Professor of Orthopedic Surgery, Washington University School of Medicine, St. Louis, Mo.

Dr. Paul B. Magnuson, Professor of Orthopedic Surgery, Northwestern University Medical School, Evanston, Ill.

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[2] Colonel Peterson continued to be impressed by the many noncombat amputations encountered in Army hospitals during the war. While amputations were being caused in combat, to the number of almost 15,000, civilian amputations over the war years were far more numerous and in many instances were entirely preventable. In 1954, in their book on "Human Limbs and Their Substitutes," Klopsteg and Wilson reflected the same concern in connection with their studies begun during the war (*4*): "* * * There was also recognition [at the end of World War II] of the rather startling fact that each year some 20,000 were being added to our amputee population of more than a half million."

At the symposium on amputations at the American Orthopaedic Association in June 1944, Dr. Harold R. Conn made the same point (*5*). There were no industrial statistics available, he said, but limb-makers were turning out 75,000 prostheses each year, and in his opinion, the industrial problem was more serious than the military.

Dr. Philip D. Wilson, Clinical Professor of Orthopedic Surgery, Columbia University College of Physicians and Surgeons, New York, N.Y.

All of these consultants were members of the Subcommittee on Orthopedic Surgery, NRC; the American Orthopaedic Association; and the American Academy of Orthopaedic Surgeons. Dr. Abbott and Dr. Conn had been in service in World War I, and Dr. Conn, for a time, had been in charge of the amputation service at Walter Reed General Hospital, Washington, D.C.

PROVISION OF PROSTHESES

At the beginning of U.S. participation in World War II, the system in effect before the war for the management of amputees was continued. That is, the Army and the Navy were responsible for their surgical and early postamputation care, and the Veterans' Administration was responsible for the subsequent care of those unfit for continued military duty. It soon became apparent, however, that the Veterans' Administration could not possibly handle such a workload in wartime, and in August 1943, the system was changed and the Army was made responsible for the definitive care of all its casualties, including amputees, in accordance with the Army regulation that no patient should be discharged from a hospital until he had received maximum benefits (*8*).

In the meantime, the care of amputees was based chiefly on the recommendations made to The Surgeon General on 30 January 1942 by Col. (later Maj. Gen.) Norman T. Kirk, MC, then Chief of the Surgical Service at Walter Reed General Hospital, who had served at two amputation centers after World War I (*9*):

1. Certain general hospitals should be designated as amputation centers.
2. Amputees with disarticulations at the shoulder and hip should be discharged at once to the Veterans' Administration for fitting with permanent-type prostheses since, after such operations, shrinkage of the stump is not necessary before fitting.
3. All amputees with lower extremity stumps should be instructed in the use of their prostheses, so that, on separation from service by Certificate of Disability for Discharge, they can walk without crutches or canes. Upper extremity amputees should have the same sort of training and should be able to dress themselves, write, and perform other personal duties before their discharge.
4. Fiber prostheses for upper and lower extremities, manufactured by the Minneapolis Artificial Limb Co., Minneapolis, Minn., should be standard. These prostheses were the cheapest and most generally satisfactory then available. They had been used continuously at Walter Reed General Hospital since World War I and had sometimes been used at Letterman General Hospital, San Francisco, Calif.
5. Forearm and upper arm amputees should be fitted with temporary prostheses of the utility type, equipped with a split hook of the Dorrance type, the hook to be interchangeable with a wooden or rubber hand covered with a chamoisette glove.
6. Each lower-extremity amputee should be given three woolen socks, of the best grade, for his stump.
7. Contracts should be entered into with the Minneapolis Artificial Limb Co.

for upper and lower extremity prostheses; with the John J. McCann Co., Burlington, N.J., for woolen socks, rubber and wood artificial hands, and gloves for these hands; and with D. W. Dorrance, San Jose, Calif., for the Dorrance split hook, complete with frame and connections.

8. If these contracts were consummated as recommended, the commanding officer of each amputation center should be authorized to order the items specified directly from the manufacturers, and funds should be allotted to the medical supply officer of each station to pay properly authenticated vouchers for them.

At the 24 February 1942 meeting, the Subcommittee on Orthopedic Surgery, NRC (*10*), supported Colonel Kirk's recommendation. It moved and passed that "* * * the same organization for the making and application of artificial limbs used at the Walter Reed General Hospital during the last war, be continued during this one."

In June 1944, the program for provision of prostheses was operating as follows (*3*):

1. Parts for upper extremity prostheses were being purchased from the Dorrance, Hosmer, and Becker Companies and from the Miracle Arm Co. of Chicago, Ill. The policy regarding upper extremity prostheses was to permit the amputee to select whatever attachments he thought would best suit his individual needs.
2. The fiber lower extremity prosthesis manufactured by the Minneapolis Artificial Limb Co. was standard issue.
3. Hip joint amputees were furnished permanent prostheses before discharge by a contract with J. E. Hanger, Inc.
4. Lower extremity amputees who remained in service for special reasons and required a permanent limb were furnished a commercial type of prosthesis.
5. The purchase and fitting of artificial limbs at Government expense were permitted only at amputation centers, the personnel of which must approve all purchases.

Circular Letter No. 115, of the Surgeon General's Office, issued on 25 June 1943, listed the prostheses available and gave instructions for their procurement and supply (*11*).

AMPUTATION CENTERS

Historical Note

The desirability—indeed the urgency—of maintaining a specialized service for amputees had been proved conclusively in World War I, both overseas and in the United States, where seven centers were established, with the center at Walter Reed serving as the chief center and the others serving as subcenters (*12, 13*). These centers treated a total of 2,635 amputees, 52 of whom had each sustained the loss of two limbs.

Shortly after demobilization, the amputation centers were closed and the amputees who were discharged from them as their immediate treatment was concluded were instructed to seek whatever additional care they might require from the Veterans' Administration. They obtained their limbs from the Administration and were permitted to select them themselves.

From this time until the early months of World War II, no agency or institution existed in the United States that could properly be called an amputation center. From the standpoint of essential experience, this was a most unfortunate situation. The amputation centers of World War I, like those of World War II, served as training centers for medical officers, not only in surgical techniques but also in postoperative management and rehabilitation. Moreover, the amputation centers offered facilities for training in the fabrication and fitting of artificial limbs and for the scientific evaluation of prosthetic appliances. In civilian life, in contrast, prostheses were purchased on an individual basis from local manufacturers.

As a result of these circumstances, modern methods had been applied to the construction of prostheses on only a limited scale before World War II, and no organized research program existed.

Establishment of Centers in World War II

The situation described could not long meet the demands imposed by a global war. Casualties occurred in mass numbers as campaigns were developed, and amputees were evacuated to the Zone of Interior in correspondingly large numbers. Facilities had to be created promptly to meet this demand, and experienced medical officers and enlisted men had to be found or trained to staff them. Obviously, as already pointed out, the Veterans' Administration had neither the facilities nor the personnel for such a workload.

The first provision for the special care of amputees in World War II was contained in War Department Memorandum No. W40–9–43, issued on 6 March 1943 (*7*), which designated the following five hospitals as amputation centers:

Bushnell General Hospital, Brigham City, Utah (Lt. Col. Ernest E. Myers, MC, Chief of Section).

Lawson General Hospital, Atlanta, Ga. (Maj. Edward C. Holscher, MC, Chief of Section).

McCloskey General Hospital (Lt. Col. Philip O. Pelland, MC, Lt. Col. James J. Callahan, MC, and Maj. Harry D. Morris, MC, Chiefs of Branch).

Percy Jones General Hospital, Battle Creek, Mich. (Lt. Col. (later Col.) Francis M. McKeever, MC, Chief of Section).

Walter Reed General Hospital (Lt. Col. T. Campbell Thompson, MC, and Maj. Donald B. Slocum, MC, Chiefs of Section).

Circular Letter No. 91, Surgeon General's Office, issued on 26 April 1943, directed that amputees be transferred as soon as possible after primary amputation to the general hospitals designated as amputation centers, for revision of their stumps and fitting of their prostheses (*14*). They were usually safely transportable within 2 weeks. It was contrary

to regulations to hold them, as some were then being held, in other general hospitals and in station hospitals until their stumps were healed and skin grafts were applied. Minor amputations (fingers, toes) did not come under this regulation unless a prosthesis was required.

Army Service Forces Circular No. 31, issued on 27 January 1944, directed that amputees be sent directly from station or general hospitals to the appropriate amputation centers without any intermediate transfer in the Zone of Interior (*15*). All amputees received from overseas were to be classified as soon as they arrived and were to be reported to the Surgeon General's Office for transfer to amputation centers.

By 1944, the five amputation centers authorized in March 1943 proved unable to handle the casualties assigned to them. There were two explanations. One was the increase in the number of casualties received from overseas as the months passed (chart 5). The second was the fact that the Army was now responsible for the revision of stumps, fitting of prostheses, and training in their use. These responsibilities required prolonged periods of hospitalization, which there was no way of shortening.

Additional centers were clearly needed to relieve the situation. The original plan was to designate DeWitt General Hospital, Auburn, Calif., for this purpose, but since the greatest need was in the eastern section of the country, the new center was located instead at the Thomas M. England General Hospital, Atlantic City, N.J.

The heavy fighting in Europe in the winter of 1944–45 led to an increase in all categories of casualties, including amputees, and a seventh center was authorized at McGuire General Hospital, Richmond, Va., in January 1945, though it did not become operational until March, after a new prosthetic shop had been completed (*16*). Maj. (later Lt. Col.) Clinton L. Compere, MC, was named Chief of Section.

Organization

Amputation centers at first were organized as subsections of the orthopedic sections of the general hospitals in which they were located. Their growth was so rapid, however, that it soon seemed more efficient to organize them as separate sections. They eventually became the largest sections in most of the seven general hospitals in which they were located.

Workload

In 1943, when the first five amputation centers were designated, a 500-bed ceiling was imposed for each, which made a total of 2,500 beds available (*16*). During the winter of 1944–45, when the heavy casualties just mentioned were being received, it was necessary to increase this ceiling several times, until it was ultimately established at 1,200 beds for

four of the five centers then in operation. At some of the centers, the actual census sometimes exceeded 1,500 beds. The maximum census, 9,246 amputees, was recorded on 30 June 1945. The increases in admissions were very rapid (chart 5): In the 10-month period ending on 30 April 1945, the census rose from 1,287 to 7,926, a sixfold increase. Not until there was a significant decrease in admissions (chart 3) did the dispositions begin to approximate the cumulative admissions.

One of the first actions of the newly appointed Consultant in Orthopedic Surgery, Surgeon General's Office, was to prove one of his most useful. It was to require monthly reports, sent directly to him, from the chief of each amputation center, showing, on a single page, admissions to the centers, dispositions, and current census; techniques of amputation employed during the period; other surgical procedures; and fittings of prostheses. Although there was originally some grumbling from hospital commanders and corps surgeons about this unorthodox method of reporting, these reports supplied invaluable, up-to-date information and permitted necessary action with the least possible delay.

Facilities

The facilities of the amputation centers were generally good and in some centers, superior. The center at Percy Jones General Hospital, for instance, was ideally suited for its functions. As the former Kellogg Sanitarium, it had been planned and built as a hospital. It was multistoried, but the elevator service was excellent and patients on crutches or in wheel chairs had no difficulty getting about. At nearby Fort Custer, there was a well-equipped prosthetic shop, with excellent facilities for work and also for training apprentices.

Under the circumstances, efficient operation was possible. In August 1945, this center had a census of about 800; and 72 enlisted men, including students, and an officer were assigned to the prosthetic shop. Either the great majority of the patients already had their prostheses or their prostheses were being processed. A course in amputation surgery was given at this center for Veterans' Administration personnel.

Thomas M. England Amputation Center

Personnel and facilities.—The history of the Thomas M. England General Hospital Amputation Center is worth relating in some detail, because it was a center that was planned as such and also because it became the largest center in the Zone of Interior.

Thomas M. England General Hospital was designated as an amputation center on 25 August 1944, and Capt. (later Maj.) Rufus H. Alldredge, MC, was ordered to it on temporary duty, as Chief of Section, on

15 July 1944. He had been informed of his pending assignment some 2 weeks earlier, which was fortunate, for it gave him the opportunity to confer on many matters with the Consultant in Orthopedic Surgery in the Surgeon General's Office and also to investigate many practical matters at the Walter Reed General Hospital Amputation Center, to which he had been assigned for the previous year.

After 2 September 1944, Captain Alldredge had the assistance of Capt. (later Maj.) Calvin K. Terwilliger, MC, who had been excellently trained in amputation techniques at the same center.

Sgt. Albert Heinrich, a trained limb mechanic, was ordered to the new center with Captain Alldredge, to make plans for the prosthetic shop, and Cpl. Joseph Fein was sent from the orthopedic shop at Walter Reed General Hopital to Percy Jones General Hospital for a month's training in the limb shop at the amputation center there. 1st Lt. (later Capt.) John W. Bishop, MAC, was placed in charge of the shop at England General Hospital. 1st Lt. (later Capt.) Minnie R. Andrews, ANC, was transferred from the Walter Reed Amputation Center to supervise the nursing service at the new amputation center.

Throughout the war, shortages of manpower and rapid changes of personnel affected the work both on the wards and in the limb shop. The situation on the wards was greatly improved when a number of Medical Administrative Corps officers were assigned to take routine administrative details off the hands of Medical Corps officers.

Thomas M. England General Hospital occupied the buildings of the former Chalfonte-Haddon Hall in Atlantic City. Its facilities were admirably adapted for the care of amputees because of its large capacity, its elevator service, and its proximity to the large metropolitan area in which many of the patients lived. The efficient bed arrangement that was possible reduced the number of medical and other personnel originally estimated as necessary to operate the center.

A space in the basement of Haddon Hall, then housing the occupational therapy department of the hospital, was designated for the prosthetic shop. The original plans, drawn up in consultation with an architect and the post engineer, were for a 20-man shop to serve a 500-bed amputation center. It was promptly realized, however, that the 3,418 square feet allotted for the shop would not be sufficient if the center were enlarged, and plans were, therefore, made for future expansion as it became necessary. The orderly expansion that occurred later was striking evidence of the efficiency of preliminary consultation on such matters.

The original plans called for four fitting rooms, 16 workbenches, and two worktables. A complete list of both standard and nonstandard items of both expendable and nonexpendable equipment, including tools and supplies, was submitted to the Medical Supply Officer at the hospital on 19 July 1944.

On the assumption that, as at the Walter Reed General Hospital Amputation Center, half the amputees would be bed patients and the other half ambulatory, 211 adjustable beds and the same number of Balkan

frames were set up on the second floor of Haddon Hall. Personnel for this floor consisted of four medical officers, 12 day and four night nurses, 24 enlisted men for day duty and four for night duty, eight civilian women, and four janitors.

Future needs were discussed with the operating room personnel. The Supply Officer was informed of the large increases in dressings that would be required, as well as the material for traction, bandages, and similar items.[3] The chiefs of the physical therapy and occupational therapy sections were informed of the heavier workload that must shortly be assumed, and increases in personnel were requested in both sections.

Initial operational problems.—In spite of the opportunities, fully utilized, for preliminary careful planning, there were many delays and discouragements. By the end of August, personnel in the prosthetic shop consisted of only six men. Four of them were efficient mechanics, it is true, but it was estimated that at least 30 would be needed to turn out the artificial limbs for the 750 amputees to be hospitalized, a 250-man increase over the original ceiling. The bed arrangements were changed to correspond with the altered workload. Increased medical and other personnel were requested, and increased equipment and tools were requisitioned.

It proved impossible to find civilian employees for the limb shop, and many of the items on the original equipment lists were put on back order, which meant that it would be 3 to 4 months before they would be delivered.

Seven amputees were admitted to the center on 16 August 1944, and 10 were admitted 2 days later. The first orthopedic surgery was performed on 31 August. The second floor, which had not been ready for occupancy when the first amputees arrived, had 24 bed patients when, on 14 September 1944, a terrific hurricane struck the area, doing incalculable damage and making it necessary to evacuate all the hospital patients (except one who was too ill to be moved) to nearby Halloran General Hospital, Staten Island, N.Y. Most medical personnel went with them and remained with them until it was possible to return on 22 October, with 140 patients. Orthopedic work had continued at Halloran General Hospital, and at the request of the personnel there, 50 German prisoner-of-war amputees were cared for by England General Hospital personnel; about 35 stump revisions were performed.

The prosthetic shop in the basement of Haddon Hall flooded so rapidly when the doors burst open under the force of water outside that there

[3] A single item, the care of bandages, will illustrate the endless detail involved in the management of this and other amputation centers. For 1,200 amputees, which eventually was the authorized census for this center, 2,000 to 2,200 elastic bandages were used daily for compression bandaging of stumps and had to be washed daily. They were washed in the hospital laundry, but they had to be dried in open corridors in the basement, which created a most untidy appearance and was undesirable for other reasons. The situation was corrected by utilizing the trays used for baking rolls in the hotel bakery, not then in use, and developing two motor driers with heating units. With these arrangements, the entire daily load of bandages could be dried in 6 hours. A great many other problems were not so readily solved.

had been no time to remove workbenches and tables to a higher level and they simply floated around, bumping into each other and against the walls. After the flood had receded, however, and the shop space had been thoroughly dried out and cleaned, it was found that all this equipment, after drying in the open air and sunshine, could be salvaged.

All tools and equipment on hand were a total loss and had to be replaced, but the previous delay in supplying what was requisitioned proved fortunate; the fact that very little had arrived when the hurricane struck greatly reduced the potential loss.

Operational activities.—The amputation center at England General Hospital continued to increase in size, and in April 1945, with a census of 1,526 amputees, it became the largest of the centers. It continued the largest during the remaining months of their operation. Its highest census was in July 1945, 1,625 patients.

The final report from this center on 31 December 1945 showed a bed allotment for 1945 of 1,200, 1,586 admissions, 920 dispositions, 180 consultations, 2,765 operations, and two deaths (one from cerebral embolism, the other from an automobile accident while the patient was on an authorized leave).

In August 1945, The Surgeon General directed the staff of the center to prepare a colored moving picture on amputations, and also to prepare the script, but the end of the war terminated this project before it could be begun. Numerous pictures were made, however, of such special procedures as the Syme amputation and other partial amputations of the foot, which were developed at this center; the work of the artificial limb shop; and the whole physical therapy and reconditioning programs.

During the operation of the center, it was visited by many orthopedic surgeons and other civilian and military medical personnel and by a number of committees such as the Fracture Committee of the American College of Surgeons in January 1945 and the National Committee on Prosthetic Devices in July 1945.

This was a very efficiently run center. When Dr. William W. Plummer, civilian Consultant to The Surgeon General, spent 3 days there in December 1945 studying the patients under treatment, he had no critical comments on its operation and his only recommendation was that an additional trained orthopedic surgeon be assigned to the staff.

Artificial limb shop.—When the center at England General Hospital first became operational, Sgt. Heinrich was put in charge of the shop, but it was soon found that his special skill and experience were too valuable to be spent on executive work, and his assignment was changed to more active participation in the fabrication and fitting of limbs and instruction of enlisted men.

Mr. Lucius Trautman, of the Minneapolis Artificial Limb Co., spent 2 weeks at the center, instructing the newly assigned enlisted men and making suggestions for organizing the shop on a production line basis, so

that each man would do a certain job on certain types of limbs, would fully understand his special duties, and would perform them under the supervision of experienced personnel.

Ideally, a prosthetic shop turned out six limbs per man per month, but the largest number turned out by any of the shops in the amputation centers was 4¾ per man. The England General Hospital Center needed about 150 limbs per month. In August 1945, 292 were fitted, this being the largest number ever turned out by an army shop. In spite of this achievement, it was impossible to produce limbs as fast as they were needed in view of the rapidity with which stumps were being revised, the shortages of manpower, and the postwar slump in morale. At the end of 1945, however, the backlog of 200 when the war ended had been reduced to 30, and it was anticipated that these patients would be handled by the middle of January 1946. At one time, personnel in the shop reached 82, and day and night shifts were worked.

There were other reasons for delay in the production of protheses in addition to those just mentioned. One was the school for training of mechanics, begun in December 1944, with five men assigned to each class. The plan was that, after 3 months of training in the limb and orthopedic shops, three men of each class would be held in the prosthetic shop at the England General Hospital Center until its requirements were met. This plan was ultimately beneficial, but training of inexperienced enlisted men slowed down the work until they had acquired a certain degree of experience and dexterity.

Still another reason for delay in the output of prostheses was an attempt to carry out research work. In retrospect, it was realized that it would have been more efficient to set aside a small unit for this purpose and permit the production of prostheses to proceed without interruption. As it was, little research was accomplished. The research program on the use of plastic materials in artificial limbs, begun in September 1945, had to be turned over to a private agency (the U.S. Plywood Corp., New Rochelle, N.Y.) after some preliminary work on it had been done because it was impossible to spare qualified personnel for it.

Clinical Considerations

Amputees treated at the Thomas M. England General Hospital Amputation Center fell into three groups (*17*):

1. Casualties who had undergone open circular amputation 6 to 12 weeks before admission and whose stumps required no revision, were completely healed, and were ready for fitting of prostheses.
2. Casualties who had undergone open circular amputation and whose stumps were clean and ready for revision or reamputation. Their stumps might be healed or unhealed, but they were unfit for the fitting and wearing of prostheses without some further surgery.

3. Casualties with complications, including osteomyelitis, with or without sequestra formation; chronic soft tissue infection; extensive dermatitis; retraction of skin and soft tissues; and flexion deformities. Most of these complications were the direct result of improper surgical technique and poor aftercare. Stumps that had been closed primarily or that had been left with flaps for delayed wound closure represented violations of official regulations for amputation in combat injuries (p. 915).

The average patient was seen within 6 to 12 weeks after primary amputation, but the range was 2 weeks to 12 months or, occasionally, longer. Some patients had multiple injuries, which sometimes took precedence of surgery on the stump.

The routine of clinical management was essentially the same as at other amputation centers. It included a general survey of the patient's status; a special study of the stump, with particular reference to the quality and duration of postoperative skin traction; routine aerobic and anaerobic cultures, repeated at intervals; roentgenographic studies; preoperative preparation with emphasis on skin traction, exercise, and compression bandaging of the stump; such surgery as was indicated; physical and occupational therapy; and reconditioning.

The facilities at England General Hospital were particularly well adapted for intensive reconditioning. The plan used at certain other centers, by which a patient was not permitted to wear his prosthesis until he had developed the proper muscle balance and demonstrated his ability to use the artificial limb, was put into effect here in 1945. A large part of the reconditioning program was voluntary, and the increasing participation of the patients in it was notable and heartening. In the last months of its operation, the England Center served as a center for advanced reconditioning.

A training school for Women's Army Corps technicians was conducted in the Physical Therapy Section at this center.

ARTIFICIAL LIMB SHOPS

Facilities

The artificial limb shops established at each of the amputation centers for the manufacture and alteration of prostheses were inseparable adjuncts of the clinical sections. Like the centers themselves, the original facilities of these shops were quickly surpassed, since they were originally set up for a miximum capacity of 500 amputees each, a number that was first doubled and then almost tripled.

There had been no prewar provision for these shops, and since space in all hospitals was limited, it was necessary to remodel and expand whatever areas could be used for this purpose. Some shops were set up in basements, with inferior lighting and ventilation. These makeshift arrangements were not efficient, and when McGuire General Hospital was

designated as the seventh amputation center early in 1945, the Commanding Officer, Col. Percy E. Duggins, MC, arranged for the construction of a new, separate building for the limb shop. The new facilities proved both efficient and adequate (p. 893).

The limb shops, in general, were run according to the policies used in braceshops (p. 57), but the work was of a more specialized nature.

The World War II experience with amputations proved three points clearly:

1. An adequate limb shop, with suitable lighting and ventilation, is the first consideration in the provision of artificial limbs for large numbers of amputees.

2. Only shops whose size is considerably in excess of requirements can function satisfactorily.

3. It is necessary for medical officers to understand the potentialities and limitations of these shops even better than the mechanics understand them.

Personnel

Throughout the war, the Army prosthetic program suffered from a shortage of skilled artificial limb technicians, for several reasons:

1. Even in civilian life, this was a small, highly specialized field.

2. The civilian industry promptly lost some of its younger employees to the Armed Forces and others to better paying war industries. The majority of workers who remained in the industry and who could be classified as skilled were exempt from military service either because of physical disabilities or because they were above the draft age.

3. During the early period of Selective Service, inductees with training in specialized fields were not properly classified and assigned. When the amputation program was instituted, it was, therefore, difficult to locate trained artificial limb technicians in the Armed Forces.

4. The initial shortages of workers were compounded as the number of amputees increased.

A number of attempts were made to overcome these shortages:

1. In September 1943, letters were addressed to all commercial manufacturers of artificial limbs, requesting the names and addresses of any of their former employees presently in military service. These men were tracked down and those who seemed to have sufficient experience to justify the effort were transferred out of their current assignments and into limb shops.

2. A few enlisted men experienced in this field who had already been sent to the European theater were returned to the United States before D-day, at the particular request of The Surgeon General, because of the critical need, and were assigned to these shops.

3. As new inductees with experience as technicians entered service, they were carefully followed until they were appropriately assigned (*18*). Technicians for both brace and limb shops were placed in a "scarce" category, which prevented their transfer overseas.

4. To augment the number of technicians needed by the limb shops, a 3-month training course for orthopedic mechanics was established at a number of general hospitals, including all amputation centers. As the men in these courses completed their training satisfactorily, they were assigned, as needed, to the amputation centers. This on-the-job training was continued throughout the war.

5. A cadre of 10 trained mechanics was provided for the centers established at Thomas M. England and McGuire General Hospitals by transferring to each of them two men from each of the five centers already functioning.

6. Mr. Trautman of the Minneapolis Artificial Limb Co. spent 10 days in each of the shops, assisting in the training of personnel.

7. A production line method was adopted by which unskilled individuals were trained in certain specific operations and in no others. This plan enabled the shops to make large numbers of limbs with a minimum of skilled help, since the time of technicians of superior skill and experience could be utilized to the best advantage for final fittings and complex situations.

8. The Surgeon General was insistent that extreme care be exercised to insure that the fittings of prostheses were entirely satisfactory and that each amputee be taught to use his prosthesis competently before his discharge. He did not wish these duties delegated to untrained personnel. It was thought that The Surgeon General's desires could be met, and additional personnel provided for the shops, if amputees could be retained in service and trained for duty in the limb shops. It was believed that these men, in view of their experience and their unfitness for full military duty, would have a keen personal interest in this work. On 3 February 1944, a letter was addressed to the commanding general of each service command, setting forth The Surgeon General's instructions and suggesting that, whenever possible, amputees, including men still in service and those already separated from service, should be employed in limb shops. On 14 March 1944, a similar letter was addressed to the commanding officers of all amputation centers (*19*).

Unfortunately, and contrary to expectations, the amputees themselves displayed very little interest in working in limb shops and even less interest in being trained for such work. Most of them preferred to be discharged, to return to civilian life and to gainful employment in their own communities. Some of them undoubtedly took this position because of fear of being retained in service indefinitely. At any rate, since it was not considered good policy to assign men to such duties against their will, the proposed program was dropped.

9. Instructions in June 1944 to place officers with previous prosthetic experience in charge of limb shops could not be carried out in five of the seven shops because officers with such training could not be located.

10. Another attempt to improve the personnel situation was also unsuccessful: To encourage qualified enlisted men to remain in service, The Surgeon General, on 12 September 1944, forwarded to the Commanding General, Second Service Command, a proposed table of ratings for each of the amputation centers, with the idea of providing ratings for the enlisted men in these shops commensurate with their responsibilities and experience and also relative to their classification in the "scarce" category (*20*). His suggestions were approved in substance, but under existing policies of bulk personnel allotment to service commands, they could not be adopted. The suggested table of organization was as follows:

One mechanic per each 75 orthopedic patients in each general and regional hospital.

One mechanic per each 30 amputation patients in each amputation center.

One mechanic per each 150 neurosurgical patients in each neurosurgical center.

The suggested distribution of ratings was as follows:

Number of mechanics in shop	M. Sgt.	T. Sgt.	T3c. or S. Sgt.	T4c. or Sgt.	T5c. or Cpl.
3 mechanics			1	1	1
6 mechanics			1	2	3
9 mechanics		1	1	3	4
12 mechanics		1	2	4	5
24 mechanics	1	1	4	8	10
33 mechanics	1	2	5	11	14

War Department memorandums issued on 25 July 1944 (*21*) and 2 February 1945 (*22*) dealt with critically needed specialists, and in March 1945, *The Bulletin of the U.S. Army Medical Department* (*23*) carried a notice that limb fitters were needed in the amputation centers and that new civilian positions, with attractive salaries, had been created. Some discharged soldiers were employed as civilians in the brace and artificial limb shops, but the shortages of trained personnel were not overcome during the war.

Section III. Meetings and Conferences

In order that maximum benefit might be derived by all the amputation centers from the work done at the individual centers, informal conferences were held at intervals during the war, usually at 6-month intervals and usually in conjunction with meetings of various orthopedic associations.

As soon as Colonel Peterson was appointed Consultant in Orthopedic Surgery in the Surgeon General's Office, he instituted informal conferences

in his office. The plan was efficient and timesaving, and was continued throughout the war and for some months thereafter.

The annual report of the Surgical Consultants Division, Surgeon General's Office, for 1944–45 lists 11 conferences attended by Colonel Peterson during this period, nine of which were either totally or in large part concerned with amputations and prostheses (*16*).

PANEL ON AMPUTATIONS

29 July 1943.—The first actions of the Subcommittee on Orthopedic Surgery, Committee on Surgery, Division of Medical Sciences, NRC, in respect to amputations were taken at the meeting of the subcommittee on 29 July 1943 (*24*). Two types of artificial limbs demonstrated by Colonel Kirk were approved, and Circular Letter No. 115, Surgeon General's Office (*11*), which outlined the system for provision of prostheses, was also approved. It was suggested informally, and agreed to by representatives of the Veterans' Administration present, that the administration set up centers over the country for the necessary reconstructive surgery on stumps and for fitting of prostheses, these centers to be modeled after the Army amputation centers.

8 September 1943.—These proposed centers were discussed again at the meeting of the Panel on Amputations, Subcommittee on Orthopedic Surgery, on 8 September 1943 (*25*). It was suggested that, at each center, a small shop be established for the repair of prostheses and for minor alterations on them, the work to be done under the direction of surgeons specially trained in amputations. It was also suggested that surgeons in charge at these centers be given the opportunity for training at Army amputation centers. It was considered both expensive and impractical, however, for the Veterans' Administration to handle its own prostheses. The Administration tried to require 3 years of service from the prostheses which it furnished, but the period varied from a matter of months to 10 years, depending upon the stump, the fit of the prosthesis, and the attitude of the particular patient.

Plans were made at this meeting for the preparation of a reference manual on amputations, to cover such items as prostheses, rehabilitation, and painful or otherwise unsatisfactory stumps. This manual would supplement General Kirk's monograph on amputations, which had just been revised (*26*) and which, for its scope, was considered ideal.

Plans were also made for trips to Canada and England, by representatives of the Army, the Navy, and the Veterans' Administration, to study organization of amputation centers, surgical practices, and new developments in prostheses.

19 November 1943.—At the 19 November 1943 meeting of the Panel on Amputations (*27*), it was decided that it would be more practical not

to initiate a new manual on amputations but instead to forward to General Kirk, for his consideration and possible inclusion in his own monograph, any new material discovered or developed by the panel. It was recommended that an educational film be prepared, demonstrating the fitting of prostheses and the physical rehabilitation of amputees, the film to be prepared with the available facilities of the Army and the Navy and to be offered to the Armed Forces, the Veterans' Administration, and civilian medical organizations.

At the beginning of this meeting, Col. Rex L. Diveley, MC, formerly Senior Consultant in Orthopedic Surgery in the European theater, had shown two colored films: one dealing with below-knee amputation at Roehampton, the British central amputation center, which, up to this time, had handled 62,000 patients; and the other dealing with the activities of a British rehabilitation center.

At this meeting, the plan of the Association of Limb Manufacturers of America, Inc., for the establishment of a research center was presented (p. 895), and plans for a comprehensive training course for orthopedic mechanics were also presented. Both plans were commended, but it was pointed out by the chairman of the panel, Dr. Philip D. Wilson, that the panel had no authority to do more than indicate its approval. Neither of these plans was implemented.

19 May 1944.—At the 19 May 1944 meeting of the Panel on Amputations (*28*), there was further discussion of the training program for mechanics just mentioned, but the chief business of the session concerned problems connected with Veterans' Administration participation in the amputation program.

30 January–1 February 1945.—The Conference to Standardize Artificial Lower Limbs, held under the auspices of the Panel on Amputations in Chicago on 30 January through 1 February 1945 (*29*), is discussed in detail elsewhere (p. 896). It grew out of the request of The Surgeon General in December 1944 that the Panel on Amputations set up a program for improvement and standardization of prostheses.

18 January 1946.—When the Panel on Amputations met in Chicago on 18 January 1946 (*30*), Dr. Wilson opened the meeting by stating that, as far as the amputation problem was concerned, it was "almost the end of the war." The minutes of this session constitute a very valuable postwar discussion of amputations overseas and in the Zone of Interior in World War II. A careful perusal of this record is highly recommended.

ARMY CONFERENCES

29 May 1943.—The first of the informal conferences dealing with the activities of the amputation centers was held at the center at Walter Reed General Hospital on 29 May 1943, immediately following the annual meeting of the American Orthopaedic Association in Cleveland, Ohio. In addi-

tion to the chiefs of the centers, the conference was attended by Brigadier General Kirk, who became Surgeon General of the Army 3 days later; Brig. Gen. Fred W. Rankin, Chief Consultant in Surgery, Surgeon General's Office; Dr. George E. Bennett and Dr. Philip D. Wilson, representing the Panel on Amputations; and Colonel Peterson, the Consultant in Orthopedic Surgery, Surgeon General's Office. The conference was attended also by representatives of the Supply Division, Surgeon General's Office, and by representatives of manufacturers of artificial limbs. The composition of later conferences was much the same as that just described.

The discussion at this meeting chiefly concerned surgical policies and prostheses, specifications for which were not attempted. The most important decision was that a temporary or provisional limb should be fitted to each amputee as soon as possible, to permit his early discharge from the hospital after (and not before) he had been taught to use the prosthesis satisfactorily.

3 June 1944.—The principal items on the agenda of the conference held on 3 June 1944, in conjunction with the annual meeting of the American Orthopaedic Association at Hot Springs, Va., concerned surgical policies, prosthetic supply, and fitting of prostheses. The responsibility for physical therapy received special consideration, and it was recommended that this modality should be under the orthopedic section, so that surgical care could be coordinated with postsurgical preparation of the stump for the prosthesis and the training of the amputee in its use. A statistical summary was also presented of all major amputations handled in the centers between 1 January 1943 and 1 May 1944- (p. 870).

The last session of the American Orthopaedic Association was devoted to a symposium on amputations (*5*), with formal presentations by Col. R. I. Harris, RCAMC (*31*); Colonel Peterson (*32*); Lt. Col. T. Campbell Thompson, MC, and Capt. (later Maj.) Rufus H. Alldredge, MC (*33*); Colonel McKeever (*34*); and Dr. Atha Thomas (*35*). Participants in the following discussion included General Kirk, Dr. Conn, and Dr. Philip D. Wilson.

1–3 August 1945.—An Army amputation conference, under the chairmanship of the Consultant in Orthopedic Surgery, Surgeon General's Office, was held at Walter Reed General Hospital on 1–3 August 1945 (*36*). In addition to personnel from the amputation centers, the conference was attended by Col. Mather Cleveland, MC, who had just returned from service as Senior Consultant in Orthopedic Surgery, European theater, and Col. Alfred R. Shands, Jr., Consultant in Orthopedic Surgery, Army Air Forces.

The first session of the conference was devoted to a review of surgical principles of amputation, physical therapy, training in ambulation, and demonstrations of new prostheses. The research program of the recently organized Committee on Prosthetic Devices (p. 896) was outlined, and the personnel of the centers were asked to submit specific projects for it by 15 August. The new prostheses and other devices demonstrated in-

cluded crutches, a fiber ankle assembly, Celastic sockets, a harness for shoulder disarticulation, a boot for use with Boyd amputations, plastic limbs, ball-and-socket joints for arm amputees, and cosmetic gloves.

The 2 August session was held at the amputation center at McGuire General Hospital, with special attention to the new prosthetic shop there and the use of aluminum for prostheses.

The concluding session was held at the Surgeon General's Office and covered summaries of previous observations and a wide variety of other matters.

INTERNATIONAL CONFERENCE ON AMPUTATIONS AND ARTIFICIAL LIMBS

An International Conference on Amputations and Artificial Limbs was held in Ottawa and Toronto, Canada, on 14–17 February 1944. It was sponsored by the Research Council of Canada, but was truly international in scope. It was attended by representatives from the Armed Forces of Canada, Great Britian, Russia, Australia, the Netherlands, and the United States, and by representatives of the British and Canadian Ministry of Pensions and the U.S. Veterans' Administration. Among those attending from the United States were General Kirk; Maj. Gen. Howard M. Snyder, IGD; Colonel Peterson; Colonel Shands; Lt. Col. T. Campbell Thompson, MC, Walter Reed General Hospital; and Colonel McKeever, Percy Jones General Hospital.

The agenda covered surgical techniques, prostheses, and methods of fitting.

Dr. Conn, who, as already mentioned, had been head of the amputation center at Walter Reed General Hospital in 1919, was particularly impressed with the presentation of the Association of War Amps and gave a very moving account of it at the symposium on amputations at the American Orthopaedic Association meeting (*5*) in June 1944.[4] Although many agreed with him that a similar organization might be useful in the United States, nothing exactly like it was formed in this country. The Bilateral Leg Amputees Club of America was founded at Bushnell General Hospital in the fall of 1945, and on 6 November 1945, The Surgeon

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[4] The War Amps of Canada, Dr. Conn pointed out, then consisted of 3,000 men (of an original 4,000) who had lost limbs in World War I. He considered the dinner at which they had made their presentation the "most amazing and inspiring" he had ever attended. They desired no pity. They wore their artificial limbs proudly, as badges of honor, fully cognizant of the sacrifices they had made for their country. "They have helped each other to face life and the future with brave hearts," Dr. Conn went on, and they were teaching the amputees of World War II to do the same. The organization received from overseas the names of all amputees and the levels of their amputations. Two similarly maimed men then called upon the next of kin to prepare them for the return of the amputee. Delegations of Amps met every convoy, so that, before he reached the hospital, each amputee found himself already "a member of a courageous band" who understood his problems and would encourage him to seek rehabilitation. "Until some similar society of proud War amputees has been sponsored," Dr. Conn concluded, "* * * we will not have done our full duty as physicians to our steadily growing list of war victims."

General addressed a memorandum to the Commanding General, Army Service Forces, in which he conveyed the willingness of some 10 of the membership to visit other amputation centers before their discharge from service (*37*). General Kirk made certain suggestions for such a trip and pointed out that it would not only improve morale among the amputees, but would also have considerable value in counteracting the unfavorable publicity which the prosthetic program had received. No action was taken on the proposal.

After the Canadian meeting, Dr. Langdale Kelham and Mr. George Perkins, Ministry of Pensions, Great Britain, visited Walter Reed General Hospital Amputation Center; Dr. Kelham also visited the center at Percy Jones General Hospital.

Section IV. Visits and Tours of Inspection

VISITS BY CIVILIAN CONSULTANTS

Each of the five amputation centers first established was visited by one or more of the civilian Consultants in Orthopedic Surgery to The Surgeon General in May 1944, and all seven were visited in October 1945. Detailed reports of the visits were submitted to the Chief Consultant in Surgery, Surgeon General's Office, in June 1944 (*38*), and to The Surgeon General in October 1945 (*39*). The substance of the reports is discussed elsewhere (p. 902), but it is worth repeating here that the comments on surgery, aftercare, and physical therapy and rehabilitation were universally favorable and that it was stated, without reservation, that the accuracy of limb fitting far exceeded the expectations of the consultants and surpassed that achieved in civilian life.

VISITS BY CONSULTANT IN ORTHOPEDIC SURGERY

Violations of regulations.—On his inspection trips to hospitals not designated as amputation centers, Colonel Peterson made it a practice to question junior officers about amputation procedures and found, as late as November 1943, that many had little knowledge of levels of amputation, the technique of open circular amputation, and the risks of primary wound closure. Many of them stated that they would close the stump after an amputation for trauma or infection if the circumstances, in their opinion, were favorable.

The results of this lack of information were evident in several general hospitals. In one—in which there was no other criticism of the orthopedic service—two amputations had recently been done for osteomyelitis in World War I veterans; open circular amputation had been done at the correct level and the wounds had been packed, but long flaps had been created and both wounds had been closed within 2 weeks of the primary procedure.

Sound surgical principles had been violated in both cases, and the condition of both wounds proved it.

In November 1943, three recent open circular amputations for gas gangrene were observed at three separate hospitals. Debridement had been omitted in one case, and in the other two, the wounds had been closed primarily. Colonel Peterson recommended that the responsible officers be warned and that disciplinary action (admonition) be taken if these dangerous practices were continued.

Two amputees were found at a hospital which was not an amputation center. One of them was received from a station hospital, which should have sent the patient directly to a center. The other had undergone a high thigh amputation 8 months earlier for vascular occlusion; since the gangrene was limited to the foot, the level of amputation was regarded as unnecessarily high. It was recommended that both patients be transferred at once to amputation centers.

In a number of instances, stumps had been closed primarily when amputations had been done too high and the stumps were too short for good function. It was directed that this practice be discontinued.

At McCloskey General Hospital in 1943, five patients were observed who had sustained cold injuries on Attu and who had required amputation. The other patients received from the Aleutians had responded to conservative measures for exposure to cold (*40*).

On the whole, the amputation stumps observed at all amputation centers were in good condition, with excellent shrinkage and no flexion deformities. General recommendations for emergency amputation included:

1. Amputation at as low a level as possible, regardless of the indication.
2. Nonclosure of all wounds, with strict adherence to the other principles of open circular amputation.
3. Use of heavier skin traction on old stumps.
4. Avoidance of the tendency to leave excess muscle in leg stumps.

Prostheses.—Fittings of prostheses were generally excellent and the training program was very well conducted in most centers. At some of the centers (England General Hospital and McGuire General Hospital), the amputees had to earn the right to have their prostheses in their possession 24 hours a day. When a lower limb was ready for use, the amputee reported to the shop daily for 5 days, to try it out and to permit necessary adjustments. Then, he reported twice daily for training, and once he had demonstrated his proficiency, the limb was his to keep. This plan eliminated abrasions and excoriations of the stump, prevented habit limps and other vicious gait practices, and had a generally stimulating effect. It usually took from 10 to 12 days to train an amputee if the amputation was below the knee and from 2 to 4 weeks in above-knee amputations.

Patients with amputations of the upper extremity were given regular tests of accomplishment, and no furloughs were granted until proper skills were demonstrated.

At Percy Jones General Hospital, several patients were wearing the Hosmer forearm and were enthusiastic about it. Further observation was recommended. At the same hospital, several patients were wearing latex hands, for cosmetic reasons. The resemblance to normal hands was re-

markable. Further testing was recommended, and if the hands proved sufficiently durable and could be produced readily, steps should be taken to provide them for amputees who wished to wear them.

McGuire General Hospital Artificial Limb Shop.—The artificial limb shop at McGuire General Hospital, which was visited on 15 September 1945, was new and was beautifully equipped and arranged. It was in charge of Lt. H. B. Hanger, and its roster included 33 enlisted men and one civilian; six of the personnel were already experienced in this work. The shop had produced 68 prostheses in August and expected to produce 85 to 90 in September. The enlisted men had no ratings, which was most unfortunate, in view of their excellent work. The effect on their morale naturally was bad.

The chief of the center and the chief of the shop made weekly rounds together, to give the patients an opportunity to make suggestions and express criticisms. All criticisms were referred at once to the proper medical officers.

This shop was set up only for construction of limbs of aluminum alloy. The below-knee assembly was made of duraluminum tubing or welded sheets. The Woodall ankle mechanism was used, with a leather socket. Above-knee amputees were fitted with a duraluminum thigh piece, with an inserted duraluminum socket fitted to the stump. Thigh pieces were adjusted for length. Shin pieces, to fit the ankle assembly, were made in standard sizes, with half-inch differences in length.

The shopwork on these prostheses was good and fittings were excellent, but the limbs were annoyingly noisy. The satisfaction of the patients with them was comparable to that of patients fitted with standard fiber limbs, though it is only fair to say that all of those seen were in intermediate stages, and not in the final stages, of fitting. As far as the Consultant in Orthopedic Surgery could see, the only advantage claimed for this limb was in weight, but the saving of about a pound was chiefly in the thigh and shin pieces, not at the end of the leg, where it would be most important.

VISITS TO ARTIFICIAL LIMB MANUFACTURERS

Visits to artificial limb manufacturers doing business with the Army were part of the duties of the Consultant in Orthopedic Surgery, Surgeon General's Office (*16*). During 1944–45, he made visits to the Miracle Arm Co., Chicago (July 1944); the Minneapolis Artificial Limb Co., Minneapolis (July 1944, April and June 1945); Becker Hand Co., St. Paul, Minn. (July 1945); Western Plastics Co., Los Angeles, Calif. (October 1944); Woodall Orthopedic Appliances Co., Los Angeles (October 1944); Hosmer Co., Los Angeles (October 1944); Davies Artificial Limb Co., Philadelphia, Pa. (May 1945); and J. E. Hanger, Inc., Washington, D.C., which was visited on numerous occasions.

Section V. Research and Development

STATEMENT OF PROBLEMS

The problems associated with the amputation program in World War II were excellently summarized by Colonel Harris, RCAMC, at the symposium on amputations held in conjunction with the meeting of the American Orthopaedic Association in June 1944 (*31*): Before the mass experience of World War I, from which all modern amputation surgery dates, the surgeon performed amputations without much thought of how the stumps he fashioned would function with artificial limbs. The limb maker took the stump and fitted a prosthesis to it as best he could. He had no opportunity to suggest to the surgeon that certain types of stumps functioned better than others. If there had been such an opportunity, the surgeon would probably not have listened to him.

The first step of the World War II amputation program was the establishment of amputation centers in March 1943 (*7*). The second was the provision, in June 1943, for prostheses, which then could be secured only from a single company. The circular letter from the Surgeon General's Office, which described methods of procurement, also listed the types of prostheses available for the foot, leg, thigh, forearm, and arm (*11*).

At this time, prostheses for the lower extremity were reasonably satisfactory, though amputations at the hip joint presented special problems. Eventually, all such amputees were concentrated at the Walter Reed General Hospital Amputation Center, in close proximity to the manufacturer (Hanger) who provided the limbs.

Prostheses for the upper extremity, especially the hand, were far less satisfactory. Hands that were available were undesirable in respect to quality, durability, color, and general cosmetic appearance. A number of hands tested during the war had some merit, but not enough to justify their general adoption. The development of certain plastic materials, of greater promise for cosmetic covering of hands, occurred late in the war, and prostheses made of them could not be adequately tested.

There were two basic weaknesses in the amputation program. The first was that, in spite of the number of amputations performed yearly in civilian life (p. 873n), very few individual surgeons had any extensive experience with this operation.

The second weakness in the program was the practically complete lack of specifications for mass production of prostheses. This lack was in the tradition of civilian purchases, by which limbs are procured on an individual basis, but it was a fundamental weakness in any program which involved mass purchases. A contributory factor was the division of responsibility between the Army, which had the initial responsibility for the amputee, and the Veterans' Administration, which was responsible for

procurement of the permanent prosthesis and for his long-term care. Under these circumstances, research, if it had been attempted, could not possibly have been fruitful without the cooperation of all the services concerned.

As the Army amputation program expanded to involve more numerous manufacturing firms, it became evident that the quality of joints and other working parts was inferior to standards which applied in other industries. Even such minor items as rubber bumpers proved important in the function and durability of an artificial limb. Quite obviously, development in the field of prostheses had not kept pace with advances in other lines of manufacture. One explanation might have been the considerable emphasis placed over the years on the skills and techniques of limb fitting, which had tended to underrate, or at least to subordinate, the importance of the mechanical and engineering aspects of prostheses.

DEVELOPMENT OF RESEARCH PROGRAM

Perhaps the simplest way to present the extremely complicated phases of the research program is chronologically.

19 November 1943.—The problems just described were first discussed seriously by the Panel on Amputations on 19 November 1943, at a joint meeting with the officers of the Association of Limb Manufacturers of America (*27*). At this meeting, the association announced that, in an effort to assume its proper share of the present burden, it had established the Research Institute Foundation, Inc., for Scientific Research and Development in Artificial Limbs and Orthopedic Apparatus. Its board of governors represented the American Academy of Orthopaedic Surgeons; the American Orthopaedic Association; the Army and the Navy; the Veterans' Administration; the American Federation of Physically Handicapped; and its own membership. This organization, while well conceived, had neither the funds nor the personnel to carry out the excellent research program it had planned.

9 December 1944.—With the expansion of the prosthesis program, problems and difficulties multiplied. Therefore, late in 1944, Colonel Peterson, with the approval of The Surgeon General, sought to enlist the interest of other organizations. On 9 December 1944, he addressed a letter to Dr. Philip D. Wilson, Chairman of the Panel on Amputations, asking that the panel consider the establishment of a program for the improvement and standardization of prostheses (*41*). He also proposed that a conference be held to include the National Research Council, the National Bureau of Standards, limb manufacturers, scientists in various fields, and engineers, as well as representatives of the Army, the Navy, and Veterans' Administration.

27 December 1944.—The proposed plans were approved by Dr. Wilson, and on 27 December 1944, he, Colonel Peterson, Dr. George E. Bennett,

and Dr. Philip Owen, representing the National Research Council, met in Chicago to complete plans for the conference to be held in that city on 30 January–1 February 1945. At this preliminary meeting, the criticisms, recommendations, and other items requested from each amputation center were studied and consolidated. It was noted in the 1944–45 report of the Surgical Consultants Division, Surgeon General's Office, that these efforts represented the first such attempts in the United States at standardization of prostheses (*16*).

30 January–1 February 1945.—The proceedings of the Chicago conference were largely exploratory, directed toward future standardization rather than immediate action in that particular area (*42*). As one responsible participant commented later, you really could not hope to standardize anything with 70 people in attendance. Also, prostheses designed for the upper extremity were not considered sufficiently developed to justify standardization at this time. No specific recommendations were made as to mechanisms to be incorporated into standard limbs, but general recommendations were made that would serve as a basis for standardization in the future and for future research. Committees were appointed to investigate fabrics, design, and fitting, and prostheses for the hip, knee, ankle, and foot.

Part of the discussion at this conference concerned further standardization of equipment and supplies for the artificial limb shops, with particular reference to the procurement of leather and of nonstandard items, the local purchases of which had recently been sharply curtailed (p. 55). The inadequate provision of funds for this purpose had seriously impaired the efficiency of the shops. Even when a good supply system exists—and the World War II system was excellent—funds must be made available for the purchase of newly introduced items and emergency supplies. Shortly after this conference, action was taken to permit each of the amputation centers to spend up to $500 monthly for the emergency purchase of necessary equipment and supplies.

IMMEDIATE IMPLEMENTATION OF CONFERENCE RECOMMENDATIONS

Action after the Chicago conference was immediate (*43*). On 3 February 1945, The Surgeon General requested the National Research Council to set up a permanent committee to conduct research in artificial limbs for both the upper and lower extremities the study to be carried out with the full cooperation of all Army personnel and facilities. As a result of this request, the National Research Council, on 12 February 1945, formulated plans for a Committee on Prosthetic Devices, to work under the chairmanship of Paul E. Klopsteg, Ph. D., Sc. D., Professor of Applied Engineering, Northwestern University. The Committee, in addition to

Dr. Conn, Dr. Magnuson, and Dr. Wilson, civilian Consultants in Orthopedic Surgery to The Surgeon General, included:

Robert R. McMath, Sc. D., McMath-Hulbert Observatory, Pontiac, Mich.
Mieth Maeser, United Shoe Machinery Corp., Beverly, Mass.
Charles F. Kettering, Sc. D., General Motors Co., Detroit, Mich. (consultant).
Roy D. McClure, M.D., Henry Ford Hospital, Detroit (consultant).
Miles J. Martin, Ph. D., Technological Institute, Northwestern University (executive assistant).
Jeanette Lindsey, Technological Institute, Northwestern University (staff secretary).

Liaison personnel on the committee included:

For the Army, the Consultant in Orthopedic Surgery, Surgeon General's Office, with Lt. Col. John J. Loutzenheiser, Consultant in Orthopedic Surgery, Ninth Service Command, as alternate. Colonel Loutzenheiser was active in the amputation program at Bushnell Hospital and had been instrumental in getting the Northrop Aircraft Corp. to undertake research on prostheses for the upper extremity.

For the Navy, Capt. H. H. Montgomery, MC, USN, Bureau of Medicine and Surgery, with Capt. Frank P. Kreuz, MC, USN, from the same bureau, as alternate.

For the Veterans' Administration, Col. Edwin J. Rose, MC.

For the National Bureau of Standards, Mr. W. F. Roeser.

For the Federal Security Agency, Mr. Donald H. Dabelstein.

This committee had both immediate and long-range objectives. The immediate aim was to assist the Army, the Navy, and governmental rehabilitation agencies in the early procurement of the best prostheses obtainable to meet the current emergency. The long-range aim was to initiate and carry on a research and development program with the ultimate objective of providing the best possible artificial limbs for all amputees, but particularly for those who had sustained their losses in war. It had been hoped originally that rapid improvements in specifications and manufacture of prostheses for military use could be effected. The task, however, proved a long-term research project that did not begin to benefit amputees until several years after the war.

There was, of course, a certain risk attached to the establishment of such a program during wartime, when theoretical perfection, however desirable, had to be subordinated to the exigencies of the situation. In July 1945, Colonel Peterson noted in his official diary that, while it was the laudable tendency of all committees to strive for the theoretical ideal, in his opinion it would be best to forget, for the moment, such matters as oscillography; to estimate stresses by correlation of height and speed of step with the body weight and other factors; and to take existing elbow, ankle, and knee designs to any firms with good reputations for machine work and see what they could do to improve them. In support of this point of view, it should be noted that these conferences and the research program which they initiated had little value for the Army prosthetic problems during and immediately after World War II. Most decisions for specifi-

cations and procurement had to be made by the Consultant in Orthopedic Surgery with whatever technical advice he could secure.

A series of meetings was held in Colonel Peterson's office in February 1945 with representatives of the Supply Service, Surgeon General's Office, certain manufacturers, and others, to draw up detailed specifications for the fabrication and use of aluminum limbs at McGuire General Hospital Center and of plastic limbs at England General Hospital Center; specifications for the centrifugally cast aluminum knee joint selected as most nearly meeting the recommendations of the Chicago conference; purchase descriptions for limbs and accessories; and a chart of stock sizes. Since provision was made in manufacturing for overlapping seams with excess material, it would be possible for all limb shops to fit almost any size desired, and in the future, only exceptional sizes should require special orders. The chart was furnished to all amputation centers and all manufacturers concerned.

At these meetings, tentative plans were formulated with the Training Division, Surgeon General's Office, to train two men from each center every 2 months in the fabrication of metal and plastic limbs. A program was also established to train mechanics at the Western Plastics Co. in the production of plastic limbs, and to train others in the production of metal limbs at five manufacturing firms on the east coast.

On 20 February 1945, the Supply Service was requested to amend existing contracts and to negotiate new contracts to put into effect these and other components of the new program. The most significant immediate change was the adoption of a standard metal knee assembly and of a metal ankle that could be used with fiber, metal, and plastic limbs. The use of these assemblies would permit interchangeability of parts among the various amputation centers and would, it was hoped, promote standardization.

The production of aluminum legs exclusively at McGuire General Hospital and the trial of plastic legs at England General Hospital would require the training of personnel and the procurement of new equipment. It was expected that conversion to the standard assemblies would begin in June 1945, but it was realized that complete transition to them would take several months—as it did.

Although the program, as stated, appeared reasonably simple, lack of general agreement on the methods and objectives, and the complete lack of engineering data, caused numerous production difficulties and, in the case of the ankle assembly, resulted in a design of inadequate strength. The mass production and utilization of the plastic limb selected were disappointing. Within the industry itself, qualified engineers worked independently of orthopedic surgeons with clinical knowledge of prosthetic requirements. Inspection was inadequate at the manufacturing level, and, to speak frankly, there was little or no enthusiasm for the program within the industry itself. Its personnel did not wish to exchange parts with each other, and they wanted no governmental interference.

In spite, however, of embarrassing delays, moderate shortages, and rather extensive breakages of the ankle assembly in various stages of development, the program did lead to definite improvement and moderate standardization of prostheses before the war ended.

LONG TERM PLANNING

The first formal meeting of the newly formed Committee on Prosthetic Devices, Division of Engineering and Industrial Research and Division of Medical Sciences, NRC, was held in Washington on 26 March 1945 (*44*). Four other meetings were held before the war ended (16 April in Washington (*45*); 14 and 15 May in Detroit (*46*); 12 June in Chicago (*47*); and 16 July (*48*) in Atlantic City). Six additional meetings were held between October 1945 and 9 July 1946 (*49–54*).

In order to carry out its long-term objectives, the committee formulated certain general fields of investigation:

1. Comparative studies of the function of normal and artificial limbs.
2. A study of available prostheses with an analysis of their mechanical features.
3. Initiation and supervision of research and development directed toward improvement, simplification and (so far as practical) standardization of artificial limbs.
4. Investigation of materials and methods used in the fabrication of special structures and mechanisms.
5. Techniques of fitting of prostheses, with the idea of simplifying and standardizing these procedures.
6. Methods of training the amputee in the use of his prosthesis.
7. Correlation of the activities of orthopedic surgeons and limb manufacturers.

The progress of the committee on these projects, it was decided, would be reported periodically to the Division of Engineering and Industrial Research and the Division of Medical Sciences, NRC.

Practically, the committee planned to proceed as follows:

1. A subcommittee of orthopedic surgeons would appraise the structure and mechanism of the artificial limbs presently available, outline faults and shortcomings, and suggest desirable functional and other improvements that might reasonably evolve in the course of the development projects.
2. A subcommittee of physicists and engineers would study the report of the surgeons and, after analyzing it, would prepare outlines of projects designed to accomplish the objectives indicated by the surgeons as necessary and desirable.
3. In the meantime, information would have been gained about the laboratories of commercial and other organizations, and from these data,

the committee would be able to select agencies apparently best suited to handle projects of special types.

4. Contracts would be negotiated with the organizations selected.

The first such contract was made in the early summer of 1945 with Northrop Aircraft Corp., a firm that had already begun work independently at the instigation of Colonel Loutzenheiser (*55*). Other contracts were let with other firms after the end of the war.

In December 1945, the projects which the Committee on Prosthetic Devices was actively investigating included (1) further development and improvement of knee and ankle assemblies, (2) materials for producing a natural-appearing hand or for coverage of a mechanical hand, (3) evaluation of the usefulness of plastics in sockets or limb sections, (4) a broad study of metals and alloys used in the fabrication of artificial limbs, (5) fabrics and techniques of manufacture and fitting for prostheses at or below the ankle, and (6) production of a motion picture record of the Army amputation and prosthetic program(*56*).

In the spring of 1945, shortly after the committee had become active, some anxiety was expressed as to whether, with the anticipated end of the war, continued financial and other support could be expected from the Army. Dr. Vannevar Bush, Director, Office of Scientific Research and Development, made specific inquiries on this point to the Secretary of War and the Secretary of the Navy. The Secretary of War replied on 27 April 1945 (*57*):

> * * * I have been greatly interested in the work of your Committee on Prosthetic Devices and also your Committee on Sensory Aids. It seems to me they have made a remarkable contribution. It is too early to determine just how postwar research for the Armed Forces will be carried forward, but I am confident when the Office of Scientific Research and Development has concluded its work, adequate measures will be taken to continue the projects if these prove to be as fruitful as they promise. I hope that these Committees will therefore continue for the present in the knowledge that they are doing work of lasting value for men in our armed services.

At the eighth meeting of the Committee on Prosthetic Devices in Chicago on 16 and 17 January 1946 (*51*), Col. Tracy S. Voorhees, JAGD, Assistant to the Secretary of War, offered the continued cooperation of the Secretary's office and made several specific suggestions as to help that was available from it in respect to legal assistance, especially concerning patents, and budgetary and other matters.

Throughout the life of the committee, the National Bureau of Standards gave invaluable assistance in the preparation of specifications and in the testing of materials. The development and evaluation of methods of bonding aluminum to fiber were greatly facilitated by its cooperation. Engineers attached to the Surgeon General's Office also rendered valuable service in coordinating the work of the Army program and that of the contractors functioning under the committee.

OTHER ACTIVITIES

In March and April 1946, as part of the research effort, an Army Commission on Amputation and Prostheses visited England, France, Germany, Switzerland, and Sweden. It was headed by Colonel Peterson, and its other members included Dr. Klopsteg, Major Alldredge, Mr. Edmond M. Wagner, Consultant in Engineering, NRC, and Lt. Col. Robert G. F. Lewis, of the Surgeon General's Office. The visits of the commission to amputation centers and limb shops resulted in many useful ideas (*58*). In Germany, cineplasty for the upper extremity and suction sockets for the lower extremity attracted the particular interest of the commission and led to an expansion of the research program in the United States along these lines.

In August 1945, just as the war ended, a completely equipped research laboratory for the prosthetics program was set up at Walter Reed Army Medical Center, with the objective of centralizing the entire program in this location. When the amputation centers at Thomas M. England, McGuire, and McCloskey General Hospitals closed in the spring of 1946, the equipment and personnel necessary for a continuation of their research work were transferred to the new laboratory. The activities of this laboratory are included in the terminal research reports (*59*) of the Committee on Artificial Limbs.[5]

Section VI. The Amputation Program and Public Relations

INITIAL PUBLIC COMPLAINTS AND ARMY REACTION

In view of the psychologic effect on the amputees of the loss of a limb and the genuine (and admitted) deficiencies in the prostheses available, it is not surprising that the prosthetic program should have given rise to public criticism early in U.S. participation in World War II. Amputees presented special problems because of the prolonged period of treatment necessary and the emotional as well as physical disturbances resulting from the loss of a limb. The sudden congregation of so many of them, with their special problems, as well as the difficulties associated with fitting prostheses and training the amputees in their use, soon constituted a public relations problem of considerable magnitude.

Correspondence addressed to The Surgeon General, as well as news and editorial comments in the press, became increasingly critical of the whole Army program and especially of the prostheses provided. The steadily growing file of headlines and of newspaper and other articles was a constant reminder to those in charge of it of the importance of the public

[5] At the present time (1970), this laboratory, which is named the "Army Medical Biomechanical Research Laboratory," operates under the jurisdiction of the Medical Research and Development Command.

relations aspect of the amputation program.

In May 1944, General Kirk felt obliged to respond to Congressional and other criticisms of the Army by pointing out that it was the Veterans' Administration, not the Army, that had the long-term responsibility for prostheses and amputees (*11*); that the critics were in error in a number of respects, including the weight of the thigh prostheses presently being furnished; and that the whole task could probably be better accomplished by a civilian group of experts, working under the National Research Council, with their finances underwritten by the Government (*60*).

FIRST INSPECTION OF AMPUTATION CENTERS BY CIVILIAN CONSULTANTS

Arrangements were also made in May 1944 for the civilian Consultants in Orthopedic Surgery to The Surgeon General (p. 873) to inspect all five amputation centers then in operation and to report their observations formally. This report was sent to the Chief Consultant in Surgery, Surgeon General's Office, Brigadier General Rankin on 7 June 1944; transmitted by him to The Surgeon General on 24 June 1944; and transmitted by him to the Chief of Staff, Army Service Forces, on 26 June 1944 (*61*).

Each consultant made one or more visits to each of the five amputation centers, studying surgical procedures and techniques in the operating rooms, the status of the wounds and the condition of the stumps of all the amputees, procedures and equipment in all the artificial limb shops, the ability of the amputees to use their limbs after fitting, and physical therapy and reconditioning. The consultants also talked with the patients as physicians and attempted to evaluate both the type of service rendered them and their attitudes and morale.

The report of the inspecting physicians could scarcely have been more favorable in every detail. They were impressed with surgical techniques. They encountered almost no flexion deformities, limitation of movement at the hip and knee joints, or atrophic musculature. They noted few instances of causalgia, phantom limb, or painful neuroma, and also an absence of severe trophic disturbances of stumps. These results were attributed to the excellence of the primary surgery and the immediate after treatment.

The physical therapy employed was adjudged simple and effective. At all but one center, it was under the close control of orthopedic surgeons, and it was recommended that at this center, as at the others, the ward surgeon should retain the responsibility for it. Ward surgeons were performing their duties admirably.

The provisional prostheses in use were considered a great improvement over the plaster pylons used in World War I, with which some of the civilian consultants had had a personal experience (p. 860). The

fiber limb prescribed by the Army was regarded as the best appliance for the purpose. The consultants considered the fitting of these amputees better than similar fittings in civilian life. The spirit of friendly cooperation between limb-fitters and patients was commended and helped to explain why a far higher percentage of Army amputees were using their limbs efficiently than was true among civilian amputees.

The amputees were carefully informed of all aspects of their condition and of their future course. The advice of the Subcommittee on Orthopedic Surgery, which was followed in the amputation program, was considered sound.

In his letter of transmittal to The Surgeon General on 24 June 1944, General Rankin called attention to the academic positions held by four of the civilian consultants and the membership of all of them on the Subcommittee on Orthopedic Surgery, and in the American Orthopaedic Association and the American Academy of Orthopaedic Surgeons (*61*). It seemed to him "* * * that this information in a covering letter would be very convincing evidence of the abilities of these men to accept the amputations and prostheses situation and convey to lay-professional minds the impression that the Surgeon General's Office is doing a good job on amputations including both surgery and prostheses."

INCREASE OF PUBLIC CRITICISM

General Rankin's expectations were not realized, and criticism of the management of amputees became even more vocal. The critics, for the most part, were unaware of the research program set up in December 1944 (p. 895), which, it must be granted, was instituted too late, and took too long to get under way, to forestall public dissatisfaction.

On 22 June 1945, after a visit to the Office of the Secretary of War by Col. Robert S. Allen, AUS, and his adverse comments on the amputation and prosthetic program, General Kirk addressed a memorandum to the Under Secretary of War, in which he made the following points (*62*):

1. The amputation program was established on the principle that the Army should provide the amputee with full surgical care, fit him with an appropriate provisional prosthesis in preparation for fitting of a permanent limb, and train him in the use of the limb. The prostheses provided were, in all instances, those approved by the Panel on Amputations.

2. Although research and development in prostheses did not seem to be the function of the Army Medical Department, whose program was essentially limited to the wartime emergency, the Army had instituted such a program in December 1944. The conference called to initiate it was requested to set up immediate improved standards for army prostheses and to promote general improvement and standardization in them.

3. Within the next 2 months, all amputation centers would have available artificial limbs incorporating the new specifications devised in

February 1945 (p. 898). The present delays were due to reasons of manufacture and supply.

4. The Committee on Prosthetic Devices appointed in February 1945 had adequate representation on it of all interested agencies within and without the Army and Government, and the program was now in effect on a national scale.

5. Evidence from disinterested Consultants in Orthopedic Surgery indicated that the Army amputation program was more effective than that in any other country, including Germany.

6. The army films for amputees were accurate documentaries and did not represent "false advertising," as Colonel Allen had described them. When he made this charge, he had not seen the films and he refused a special invitation to view them. (At the 12th meeting of the Committee on Prosthetic Devices (by which time it had become the Committee on Artificial Limbs), it was announced that Colonel Allen had agreed to serve on the committee as Consultant on Public Relations (*63*). His forceful efforts helped to stimulate the creation of the research program at Walter Reed Army Medical Center.)

ESTABLISHMENT OF ARMY RESEARCH PROJECT

On 14 July 1945, The Surgeon General was directed by the Secretary of War to establish an Army research program on artificial limbs (*64*). This project was to be in addition to the similar program set up in February 1945 and being carried out by the Committee on Prosthetic Devices, which was functioning at the request of The Surgeon General and with the cooperation of his office.

On 7 August 1945, The Surgeon General sent to the Commanding General, Army Service Forces, the program established in compliance with the 14 July order of the Secretary of War on the research and development of artificial limbs, together with a memorandum in which he summarized Army activities to date along these lines (*65*):

1. When the need for artificial limbs in large numbers arose, The Surgeon General had adopted the only model readily available in sufficient numbers to meet Army needs. The limb selected was approved by the Panel on Amputations. The plan of fitting the amputee with a provisional prosthesis was considered superior to discharging him to the Veterans' Administration without fitting, which was the plan in Allied Armies.

2. There had never been any national program for research in artificial limbs, and standardization did not exist. The production of prostheses was scattered among several hundred manufacturers, whose outlook was highly competitive and commercialized.

3. The Research Institute Foundation, established by these firms in

1944, had proved ineffective, chiefly because of lack of funds and personnel.

4. Late in 1944, it became evident that if improvement in prostheses was to occur, governmental agencies must undertake it, and must carry it out while large numbers of amputees were concentrated in amputation centers. The activities of the Committee on Prosthetic Devices to date were described in some detail, including the changes in specifications that had followed its first meeting. Studies currently under way were listed. The work of this committee was not classified as a research project, but in effect it was.

5. In view of the facts just stated, The Surgeon General expressed the opinion that it would not be wise to duplicate the studies already under way by the Committee on Prosthetic Devices. Its members believed that their own position would be subordinated by the creation of another program, and it was believed that some of them might withdraw and the important work underway might be held up.

The program submitted by The Surgeon General in compliance with the orders of the Secretary of War was approved by the Commanding General, Army Service Forces, on 4 September 1945, 20 days after the end of the war. It was fully realized that the plans proposed would be limited by the early closure of the amputation centers and the loss of skilled personnel by demobilization. On 13 August 1945, Major Compere, Chief of the Amputation Center, McGuire General Hospital, had called Colonel Peterson's attention to these probable difficulties (*66*). The research program, he pointed out, required the cooperation of the aircraft industry, and at the Northrop Aircraft Corp., some 15 qualified engineers had been assigned to work on the improvement of knee and ankle assemblies before the company had received a contract for the work (p. 900). The activities, he believed, would fit well into the careers of qualified civilians, but would not have much interest for an Army officer since, if he were to be effective in the program, he would be kept in a position where he had little chance of advancement.

SECOND INSPECTION OF AMPUTATION CENTERS BY CIVILIAN CONSULTANTS

On 10 October 1945, Drs. Conn, Magnuson, and Philip D. Wilson transmitted to The Surgeon General their report of a second inspection of the amputation centers at Percy Jones, Bushnell, McCloskey, Lawson, McGuire, and Walter Reed General Hospitals. The report, which was transmitted to the Secretary of War by General Kirk on 6 November 1945, also included the report of a visit to the Northrop Laboratories (*67*). The physicians made their visits in their dual roles as members of the Committee on Prosthetic Devices and as civilian Consultants to The Surgeon General. Their report confirmed previously expressed opinions of the

excellence of the surgical treatment and prosthetic fitting amputees were receiving.

The report concluded:

> Finally, your Consultants wish to compliment the Army Medical Corps on having solved an extremely difficult war time problem in a more efficient manner than could possibly have been done had these unfortunate war victims been referred to civilian fitters. It should be pointed out that the Army had to prepare organized services for an unknown number of amputees. Fortunately, the war ended before their number exceeded 14,000 but if it had been two or three times as many, the services were such that all could have been handled with the same good care, expedition and good results. We feel that exceptional commendation is due the Surgeon General and the Medical Department of the Army for having successfully handled an emergency problem the like of which had never previously been encountered in modern times.

CONGRESSIONAL HEARINGS

Congress, through its Committee on Labor, Subcommittee on Aid to Physically Handicapped, conducted extensive hearings on the manufacture and development of artificial limbs. The prepared statement of the Consultant in Orthopedic Surgery, Surgeon General's Office, given in testimony on 11 September 1945, included (*68*):

1. A history of the Army amputation program.
2. The census of amputees at the various centers.
3. The problem of shortages of skilled prosthetic mechanics and the measures taken to solve it.
4. Policies of supply and fitting of prostheses.
5. The need for a coordinated research program to obtain the best possible prostheses for Army amputees, and the measures taken to meet this need.
6. The interest and concern with which the Army Medical Department had attempted to discharge its responsibility to war amputees.

The statement of the Consultant in Orthopedic Surgery appears in full in the record of the subcommittee hearing.

It is gratifying to report that the early dissatisfaction of the amputees soon disappeared as they became proficient in the use of their prostheses and returned to civilian life. Also, they came to realize that the treatment they had received in the amputation centers was superior in every respect.

Section VII. Philippine Amputation and Prosthetic Unit

An unfortunate result of the rapid withdrawal of U.S. Army troops from the Philippines at the end of the Pacific fighting was the hardship it worked on the Philippine Army, including the Scouts. The medical

care of Filipino troops, guerrillas and civilians, by Filipino personnel was entirely inadequate at this time because of the almost total destruction of local medical services during the Japanese occupation. U.S. Army personnel who were aware of the many Americans whose lives had been saved by Filipino troops and civilians, often at heavy cost to their rescuers, were greatly disturbed by the situation (*69*).

Among those who felt strongly on this matter was Col. I. Ridgeway Trimble, MC, Consultant in Surgery, Southwest Pacific Area (*70*). Acting on the principle that these troops were entitled to the same care as U.S. Army amputees were receiving, he made several recommendations on the subject to the Surgeon, Armed Forces, Pacific, on 7 December 1945:

1. Additional technicians should be provided to supplement the single technician then working in the braceshop set up in the 313th General Hospital in Manila.
2. Additional technicians should be assigned to instruct Filipino Army personnel in the operation of the braceshop that had already been sent to the Philippines from the Zone of Interior.
3. The 20 or more Scouts then in need of prostheses should be sent to amputation centers in the Zone of Interior for plastic procedures on their stumps followed by provision of artificial limbs.
4. Numerous civilian personnel in the Philippines were in need of further surgical care after amputation, as well as of prostheses. A supply of prostheses should be sent from the Zone of Interior, with a fully trained technician to measure these amputees for their prostheses after the surgery they required had been carried out.

For logistic and other reasons, it was not possible to implement these recommendations immediately, but on 18 April 1946, a complete unit, organized by the Consultant in Orthopedic Surgery, was dispatched by The Surgeon General to establish an amputation center for Filipino amputees. Its personnel consisted of Lt. Edward S. Brown, MC, Capt. John J. Keys, MC, Lt. Roger Noden, CAV, and Lt. Carol Strange, MDPT. One of the officers was an amputee. The unit also included two occupational therapists, one physical therapist, and 16 enlisted men trained in limb fitting. Within a month after its arrival, it was operating as a fully equipped and staffed amputation center, and before its personnel returned to the United States in October 1946, it had performed 94 operations, fitted 118 prostheses, and treated 192 other amputees. When the unit departed, its facilities were turned over to local authorities, to supply the needs of the remaining military and civilian amputees. The Filipino personnel left in charge had been trained by U.S. personnel and were entirely capable of operating the unit.

It was found that, in the Tropics, aluminum was better for prostheses than either fiber or wood. Thermosetting plastics were used for sockets and accessories as soon as supplies could be secured; they proved more

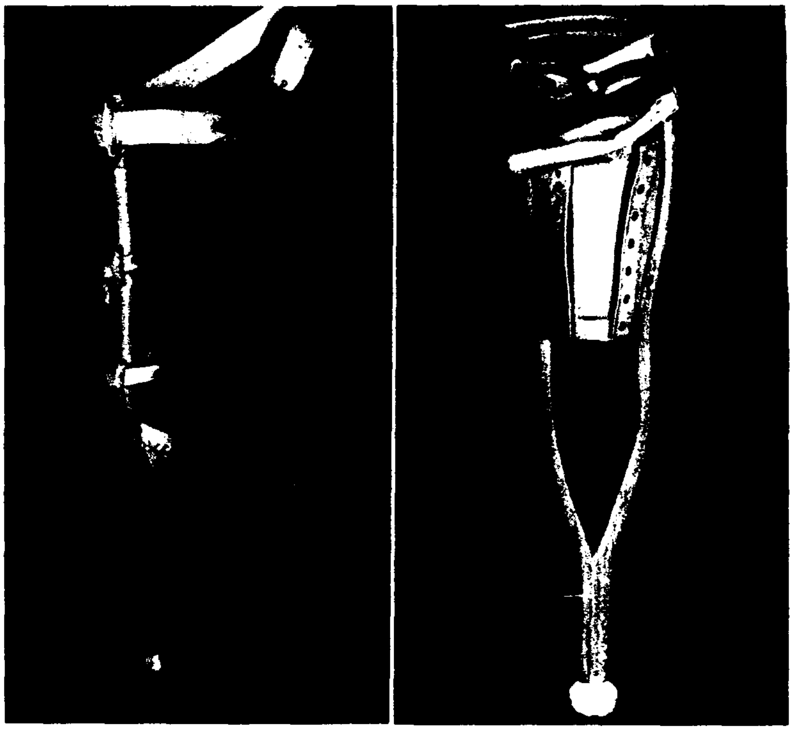

FIGURE 210.—Temporary peg-leg type of prosthesis for lower extremity designed for immediate use in occupied or other foreign territory. (Left) Bent-knee type. (Right) Ischial-bearing type for above-knee amputation.

satisfactory than the leather used for the first prostheses.

The simplest immediate solution of the problem of leg amputees in all occupied territories was the temporary use of a peg leg (fig. 210). The model for this leg was developed at the amputation center at Walter Reed General Hospital. Illustrations were sent to all active theaters of operations, where the leg proved very useful.

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CHAPTER XXXI

General Clinical Considerations of Amputation

Leonard T. Peterson, M.D.

OPEN CIRCULAR AMPUTATION

The open circular (so-called guillotine) technique of amputation was the routine procedure in World War I (p. 849) and had been advocated thereafter by military surgeons as the procedure of choice in emergency amputations for trauma and infection. It was based on three principles, (1) amputation at the lowest level that would permit removal of all devitalized and contaminated tissue; (2) nonclosure of the wound; and (3) the immediate application of skin traction, which was continued until the stump was healed.

This technique had a great many advantages. It saved more of the extremity than any other method did. The raw surface exposed was not large and had a good blood supply. No devitalized tissue was left in situ, so infection had little encouragement to persist or spread. If traction was constant, healing proceeded steadily; muscles and deep fascia became adherent to the bone; and scar tissue formation in the open wound tended to pull the soft tissue over the end of the bone. The result was a firm, smooth, conical stump, repair of which was usually quite simple. Finally, a prosthesis could be fitted shortly after the revision operation, as much of the atrophy and fibrosis that are part of the normal healing process had already occurred. In short, by the use of the open circular technique, most complications of amputation were avoided.

Despite its advantages, this technique had not been widely taught or practiced in civilian hospitals in the United States between the World Wars. It was not uncommon, therefore, in the early months of the Second World War, to observe casualties who had been treated by surgeons with little experience in amputations who violated the principles upon which the open circular operation was based. A fundamental error, perhaps to be attributed to the general use of the term "guillotine," was a complete misinterpretation of the technique. Instead of performing the operation in steps which allowed for successive retraction of structures, the surgeon employed what came to be known as the meat-cleaver technique; that is, the limb was amputated by a single transection of all its tissues. As a

FIGURE 211.—Improper technique of open amputation. This below-knee operation appears to have been done by the guillotine technique rather than by the prescribed method.

result, viable skin was sacrificed unnecessarily, skin and soft tissues were shorter than the bone, and the everted cone that was produced was the exact opposite of the inverted cone in which bone shorter than the skin and soft tissues was the objective (fig. 211).

The principal errors encountered early in the war, before open circular amputation was the uniform practice, were as follows:

1. Primary closure of the stump, which required the sacrifice of stump length and introduced the risk of infection. Primary closure may be successful in emergency amputations in occasional selected cases in civilian practice, but it is totally contraindicated in military surgery, in which failure may be attended by such serious consequences as cellulitis, osteomyelitis, and life-endangering clostridial myositis. Moreover, infection that occurs in a closed wound requires its prompt conversion to an open wound, which means that there is no gain at all from the attempt at primary closure.

Directives dealing with amputation provided for the preservation of as much viable skin as possible but also provided for the avoidance of long flaps that tended to close the wound prematurely. Such attempts were failures in the first combat cases of the war, from Pearl Harbor (p. 926). In a study made from the amputation centers in general hospitals in May 1944 (p. 902), it was found that 8.9 percent of the 1,670 patients (1,759 stumps) whose stumps were closed primarily developed infections, which in some instances were extremely serious (*1*). The unpredictable timelag during evacuation was in itself a contraindication to primary closure of the stump.

2. Amputation at a higher level than necessary. In a few cases in the series just referred to, amputation was performed higher than was necessary, sometimes through, or even above, the level of election for a finished stump. Directives provided that emergency amputation should be as low as was consistent with thorough debridement, and that the level of the bone lesion rather than the level of the skin wound or soft

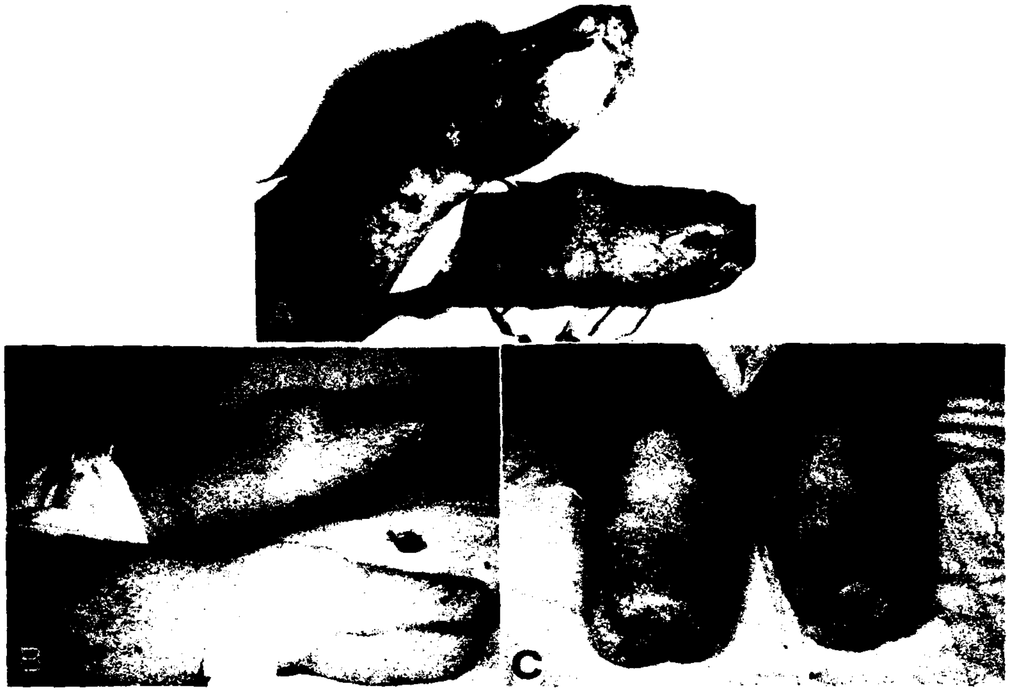

FIGURE 212.—Bilateral below-knee stumps after open amputations. A. Retraction of soft tissues in absence of effective skin traction. B and C. Almost complete closure of skin after use of continuous skin traction. These stumps can now be revised with minimal loss of length.

tissue sinus should determine the level of amputation, particularly when the stump was short to begin with.

3. Failure to use skin traction. Early, constant skin traction was an essential phase of the open circular technique. Retraction of the soft tissues was a frequent result of underestimation of its importance (fig. 212). Two measures sometimes substituted for it were not satisfactory. One was the use of a plaster cast, which was excellent as an occlusive dressing and a good means of immobilization but which did not prevent soft tissue retraction. The other measure, skin grafting, met prescribed surgical principles but did not prevent retraction of normal skin and muscles and delayed rather than expedited closure of the wound by normal skin, which was the desideratum. Since skin grafts do not ordinarily withstand the pressure of a prosthesis, they were considered indicated only under special circumstances or as a preliminary to reconstructive surgery after maximum benefits had been obtained by skin traction. They were not permitted as part of the initial management of amputation stumps.

There is a tone of distinct exasperation in Circular Letter No. 189, of the Surgeon General's Office, 17 November 1943, dealing with fractures and amputations (*2*). On a recent inspection trip by the Consultant in Orthopedic Surgery, Surgeon General's Office, three cases had been observed in which open circular amputation had been necessary for clostridial myositis that had followed primary wound closure in two cases and incomplete debridement in the other. It was strictly forbidden that any

compound fracture or extensive wound of the extremities be closed primarily.

Confusion was also evident, the letter continued, in respect to the principles of emergency amputation. Given the hypothetical case of a leg hopelessly damaged near the ankle joint, the correct emergency procedure would be guillotine (open circular) amputation at or immediately above the level of the injury; the correct procedure was not amputation in the middle third of the leg by either the open or the closed technique. Amputation for trauma was always to be circular, at the lowest possible level, and was always to be followed by skin traction. It was strictly forbidden that amputation be done higher than necessary or that the stump be closed. This technique had already been described in Circular Letter No. 91, Surgeon General's Office, 26 April 1943 (*3*).

Distribution of Circular Letter No. 189 was to all officers of the Medical Corps, U.S. Army. The commanding officers of all general and station hospitals would be held responsible for cessation of the improper procedures described and for full compliance with these directives.

INDICATIONS FOR AMPUTATION OVERSEAS

The attitude toward amputation on the part of all medical officers in forward as well as fixed hospitals overseas was one of extreme conservatism. Because of the enormous possibilities of modern reconstructive surgery, the operation was almost never performed unless the extremity was damaged beyond salvage or unless, after salvage had been attempted, conditions developed which endangered life or made further efforts to save the limb futile. The U.S. practice of extreme conservatism in the face of devastating wounds of the lower extremities was in some contrast to the policies of medical officers of other warring nations. Lt. Col. Edward T. Evans, MC, who had served with the 26th General Hospital in the North African theater in 1942, summarized the U.S. attitude toward amputation in a talk at Billings General Hospital, Indianapolis, Ind., 1946 (*4*).

> It was not given to us to decide the question of amputation except in extreme cases, but rather to save the limb and prepare the wound for reparative surgery. This was a difficult directive for many of us to accept at first, and I frankly admit that I questioned the rationale of saving some limbs I saw, merely because the wounds were healing. I recall the astonishment of a young Polish Orthopaedist who worked with us when he saw radical debridement of gas gangrene rather than amputation, and I think I first clearly understood the morale side in our program, when I saw the return of freed prisoners with amputations performed by other armies to prevent the spread of local infection rather than the surgical application of principles which we in our Army evolved and adhered to.

Mediterranean theater.—Indications for primary amputation at initial wound surgery in forward hospitals overseas did not differ from the in-

dications employed in civilian life except in respect to the degree of trauma. In the Mediterranean theater, they included (*5*):

1. Damage to the extremity of such a degree that future function was obviously hopeless. If part of the extremity had already been blasted off, blown off, torn off, or shot away, the surgeon's function was merely revision of an amputation that had already occurred.
2. Vascular insufficiency per se, with impending or actual gangrene.
3. Infection, usually clostridial myositis or such widespread necrosis of soft tissue that the extremity left was damaged beyond hope of function.
4. Disease, including malignant tumors, tuberculosis, and thrombosis, all of which were uncommon in an overseas theater. Damage from cold injury was also an occasional indication.

European theater.—In the European theater, the indications for amputation were listed as (*6*):

1. Total destruction of tissue, including bone tissue, of such a degree that almost complete traumatic amputation had already occurred.
2. Vascular damage, which often was inherent in the destruction of tissue. In evaluating this indication in the European theater as well as other theaters, it must be remembered that, during World War II, vascular surgery was still in its very early stages.
3. Clostridial myositis.

In the Mediterranean theater, the official surgical policy of open circular amputation was set forth explicitly in Circular Letter No. 46, Office of the Surgeon, North African Theater of Operations, 29 August 1944 (*7*). Early in the war, some surgeons in this theater were inclined to use the meat-cleaver technique, but the error was promptly corrected by educational methods. Skin traction was routine, both in the hospital and during transportation.

In the European theater, the "Manual of Therapy" (*8*), issued in May 1944, shortly before D-day, made the open circular amputation permissive in cases in which the amputation level was well within the site of election. It was also to be used when the point of bone division was at, or close to, the point of election. It was later realized, in the light of experience with combat wounds, that these directions were confusing; and in the proposed 1945 revision of the manual, they were clarified as follows (*9*):

1. There are only two absolute indications for amputation, complete destruction of the blood supply, which means the loss of a main artery, and diffuse clostridial myositis.
2. Amputation must always be performed at the lowest possible level the nature of the wound will permit.
3. The open circular technique must be used routinely. The guillotine (meat-cleaver) operation must not be used.
4. Disarticulation will be used only where there is no possibility of a more conservative procedure.

Most of the changes in the revised "Manual of Therapy" had ap-

peared in Circular Letter No. 101, 30 July 1944 (*10*), and Circular Letter No. 131, 8 November 1944 (*11*), both from the Office of the Chief Surgeon, European theater. The greater specificity of the revised instructions reflected the necessity of leaving nothing to the imagination of inexperienced military surgeons.

Wound closure.—Closure of the wound was not permitted in the European theater. This was stated specifically in the 1944 "Manual of Therapy" (*8*). In the Mediterranean theater, the policy was more permissive. Delayed closure was strictly forbidden (Circular Letter No. 46, 29 August 1944 (*7*)), in amputations of the thigh and leg unless it could be carried out well below the site of election. In amputations of the lower third of the leg and of the upper extremity, delayed closure was permitted whenever it was surgically feasible. It was applied in only a small number of cases and results were good in that there was no known instance of clostridial myositis or other serious infection after it, no reamputations were reported, and there were no fatalities.

In spite of the caution with which delayed closure was used in the Mediterranean theater, the practice was not looked on with favor in the Zone of Interior. Against its use were two points:

1. In most conservative open circular amputation, there was not sufficient skin to permit delayed primary wound closure.

2. Excellent results were achieved, when the wound was left open, by adequate skin traction, shrinkage of the stump, and later revision. It is true that open circular amputation usually required either revision or reamputation, but it is equally true that delayed primary closure of the stump did not necessarily preclude additional surgery in the Zone of Interior.

SITE OF ELECTION

The optimum levels for definitive amputation that had been established before World War II were considered acceptable in combat surgery. Generally speaking, whenever a suitable prosthesis had been devised, it was considered expedient, with a few exceptions, to save as much of the extremity as possible. The development of more adequate prostheses as the war progressed permitted a more liberal concept of a suitable stump.

In the upper extremity, it was the original policy to save as much of the arm as possible, though the elbow joint or the wrist joint was not considered useful as a terminal stump. Later, it became established policy to preserve the maximum length of the extremity, wherever the site of amputation might be. A disarticulated wrist joint proved to be an excellent stump, especially if it included the proximal row of carpal bones. It could be easily fitted; it eliminated the encumbrance of straps and hinges above the elbow; and it permitted rotary motion in the forearm. The

stump resulting from disarticulation at the elbow was fitted with a prothesis in several instances in an effort to preserve circumduction action in the arm, since the irregular expanded surface of the humeral condyles permitted firm fixation of the appliance.

In the lower extremity, the types of stumps considered acceptable in U.S. orthopedic civilian practice were the standard below-knee stump 5 to 7 inches long and the above-knee ischial-bearing stump. End-bearing stumps had had a considerable trial and had proved satisfactory, but prosthetic developments had not advanced far enough to permit as good knee control as was possible with the above-knee ischial-bearing type of limb. In a few cases of disarticulation at the knee, adequate fitting with serviceable prostheses was possible, but their maximum utilization was still to come. Commercial limb-makers looked on them with disfavor.

Commercial limb-makers also looked with disfavor upon the Chopart and Syme stumps at the beginning of the war, but the extensive and highly favorable experience of Canadian surgeons with the Syme amputation led to its early adoption in the U.S. amputation program (p. 973). Chopart amputations were of limited usefulness.

In both upper and lower extremities, the official policy was thus to perform emergency amputation at a level as low as was consistent with careful debridement, with the bone injury and not the level of the skin wound determining the level at which amputation was done. This method preserved a stump of maximum length for later revision and for fitting of a prosthesis. Greater selectivity was possible in amputations at special levels as improved prostheses became available.

TECHNIQUE OF OPEN CIRCULAR AMPUTATION

The approved technique for open circular amputation, both overseas and in the Zone of Interior, was as follows (fig. 213):

1. The skin of the extremity was prepared as for any surgical procedure.
2. A tourniquet, preferably of the pneumatic type, was applied.
3. A circular incision, extending down to the deep fascia, was made at the lowest practical level. An irregular or short-flap type of incision was permissible, especially when it was necessary to conserve skin for subsequent closure.
4. After the skin had been allowed to retract, the deep fascia was divided at the level to which the skin had retracted.
5. The muscle was divided in circular sweeps, about three-fourths of an inch being included in each sweep, so that, as the muscle retracted, the next muscle division was made at a slightly higher level than the preceding division.
6. The periosteum was incised in the same circular fashion at the level to which the last muscle layer had retracted. This level was the level which had been selected for the amputation when the operation was begun.
7. The bone was sawed through cleanly at this level. The periosteum was neither

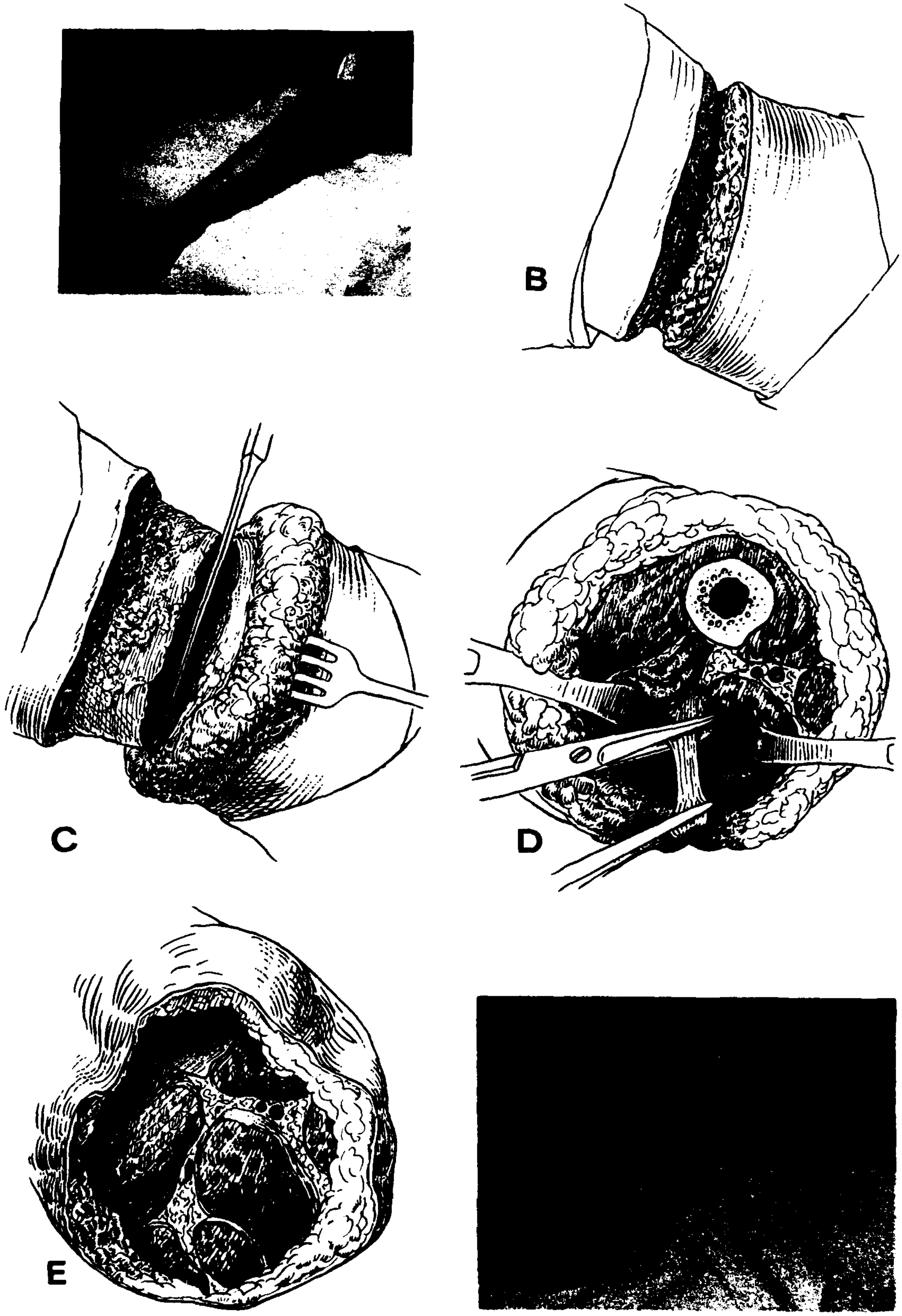

Figure 213.—*See opposite page for legend.*

stripped nor elevated, and no attempt was made to remove it at a level higher than the saw cut.

8. The nerves were pulled down and severed cleanly at the level of the surrounding muscle division. They were never crushed, and only the larger nerves (particularly the sciatic nerve) were ligated.

9. All large veins and arteries were doubly ligated separately, never en masse. Extreme care was taken not to include large amounts of muscle in the ligatures about small vessels. After the larger vessels had been ligated, the tourniquet was removed, the field inspected, and any residual bleeding controlled. Precise hemostasis was essential.

10. The end of the stump was covered with dry, fine-mesh gauze. Topical applications were not used. The stump was then firmly wrapped with an elastic bandage.

The immediate application of skin traction was the desideratum (fig. 213F). In some instances, because of frontline battle conditions, it was not possible to apply it immediately after operation, but in such circumstances, it was always applied as early as possible in the chain of evacuation. Otherwise, the only authorized delay in the institution of traction was its postponement from 24 to 48 hours after amputation for clostridial myositis. At the end of this time, it was possible to determine whether the wound was clean or infected; if it was clean, traction was instituted at once.

Skin traction for transportation was applied as follows:

1. After the stump had been covered with dry, sterile, fine-mesh gauze, a circular roll of stockinet was applied to it and was rolled as far as possible proximally.

2. The skin was painted with benzoin or with some adherent.

3. The stockinet was unrolled down on the stump and was allowed to adhere to the skin.

4. Traction was applied to the stockinet and additional dressings were placed inside of it. Several layers of sheet wadding were placed loosely over the stockinet, and the whole stump was firmly wrapped with an elastic bandage.

5. A circular plaster pylon, with an outrigger made of a wire ladder splint, was applied to the stump. The end of the stockinet was fastened to the outrigger by means of a short piece of elastic traction cord or, if cord was not available, by plasma tubing.

IMPROPERLY MANAGED COMPOUND FRACTURE OF THE FEMUR

Strict adherence to the directives from the Surgeon General's Office concerning the precise technique of open circular amputation was regarded as so important that, when the instructions were disregarded, as they

FIGURE 213.—Management of gangrenous right leg, with nonunion and osteomyelitis of femur by open circular amputation. A. Appearance of leg. B. Circular incision at level of nonunion. C. Incision of fascia and muscles after retraction of skin. D. Appearance of stump after removal of sequestrum at level of fracture. The sciatic nerve is being severed after ligation and downward traction. E. Final appearance of stump. Note that there is adequate skin to permit healing with skin traction. F. Application of skin traction with skin glue and stockinet.

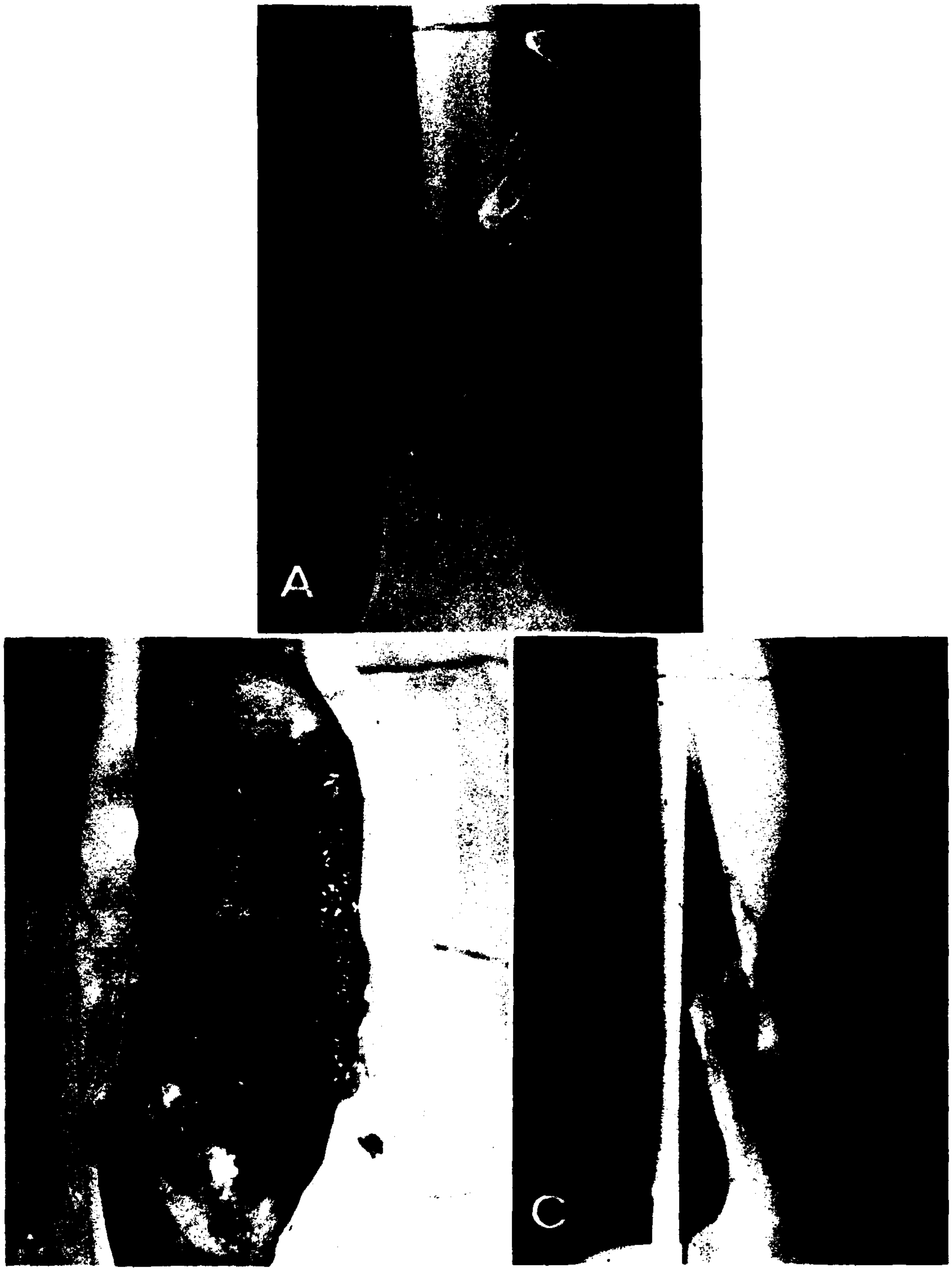

FIGURE 214.—Mismanaged compound fracture of lower third of right femur, with eventual amputation, complicated by hematogenous osteomyelitis of right humerus. A. Anteroposterior roentgenogram 24 days after injury (2 November 1944). B. Appearance of wound on arrival of patient at named general hospital in Zone of Interior 3½ months after wounding (25 January 1945). C. Lateral roentgenogram 4 months after injury (6 February 1945).

FIGURE 214.—Continued. D. Lateral roentgenogram 3 weeks later (27 February 1945). E. *Anteroposterior* roentgenogram of femur 7 weeks after closed amputation (5 May 1945).

were on occasion by surgeons in the Zone of Interior, disciplinary action (admonition) was threatened.

The following case history (fig. 214) illustrates the possible consequences of disregard of directives and of errors in judgment and treatment. In this case, the result was prolongation of hospitalization, development of serious complications, and unnecessary suffering and disability for the casualty.

Management Overseas

Case 1.—A 20-year-old private, first class incurred a compound fracture of the lower third of the right femur on 9 October 1944, during combat on the Continent. The wound was debrided at an evacuation hospital 48 hours later, and a double-hip spica was applied.

On 19 October 1944, at a numbered general hospital, the wounds were redressed and a fresh cast was applied. Roentgenographic examination on 27 October 1944, at another numbered general hospital, showed angulation and displacement of the upper fragment of the femoral fracture for half its width.

On 30 October, it was recorded that about 30 percent of the soft-tissue structures of the right thigh were missing. The wound extended from the anterolateral to the posterolateral aspect of the thigh through almost its entire length. The deep fascia was visible. On the medial aspect of the wound the muscles were missing to within an inch of the fracture site.

FIGURE 215.—Bilateral above-knee open amputation. The patient was a prisoner of war and had had no skin traction. Note the retraction of the muscles and skin and the bulbous, edematous appearance of the stumps. Revision required the sacrifice of critical stump length.

At this time, the wound was again debrided and a Kirschner wire was inserted through the tibial tubercle, followed by 15-pound skeletal traction. A week later, at the same hospital, the wire was removed, partial closure of the wound at the upper angle was attempted, and a body spica was applied. The chart gave no reason for the change of treatment, but the assumption is that evacuation was contemplated. The patient did not, however, reach a named general hospital in the United States until 25 January 1945, a little over 3½ months after wounding. Although he had been given repeated infusions and large doses of penicillin overseas, he was underweight, severely anemic, and seriously ill. Dry gangrene had developed in all the toes of the right foot but had remained localized.

Management in the Zone of Interior

Up to this point, the patient's treatment is not open to criticism.

Penicillin was resumed as soon as he reached the Zone of Interior. When the cast was changed, under general (intravenous) anesthesia, the wound had a foul odor and the soft-tissue defects exuded a heavy, purulent discharge. The ends of the un-united fracture presented in the depths of the wound. The toes of the right foot showed dry gangrene, but there was no apparent nerve damage. Extensive pressure sores were present on the heels and below the head of the right fibula.

In an effort to correct the 2-inch overriding of the ends of the fractured femur, a Kirschner wire was inserted in the upper tibia, and skeletal traction was instituted.

Amputation had been seriously considered as soon as the patient arrived in the Zone of Interior, but he refused to consent to it. It shortly became evident, however, that it could not possibly be avoided. Although the general hospital in which the patient was confined was not an amputation center, permission to perform the operation in it was obtained from the service command consultant. After careful preoperative preparation,

amputation was performed by the chief of the surgical service at the junction of the middle and distal thirds of the femur on 16 March 1945, a little more than 5 months after wounding. The surgeon stated in his operative notes that, in order to give the patient as long a stump as possible, he had preserved a long posterior flap of tissue and brought it anteriorly over the end of the stump, where he had sutured it into place loosely.

The surgeon thus made two serious errors: He created a long flap, and he closed the wound, however "loosely." These errors were promptly manifested by the patient's subsequent course. In spite of intensive penicillin-sulfadiazine therapy, it was stormy, and for 7 days, the maximum temperature ranged from 103° to 105° F.

According to the chart, the stump was kept in traction from the first postoperative day and an elastic bandage was applied, with increasing pressure, to shape it properly. These measures, in the face of clear-cut infection in the stump, were obviously premature, but, in spite of the stormy course, the surgical wound was not reopened.

On 26 April 1945, the patient was finally transferred to an amputation center, where he was seen a few days later by the Consultant in Orthopedic Surgery, Surgeon General's Office. At this time, his acute symptoms had subsided, but he appeared chronically ill, with pallor and loss of weight. The temperature was normal. The stump was not painful. It presented a transverse anterior scar and a number of sinuses that were draining purulent material and that seemed to communicate with each other at the lateral and medial borders. Roentgenographic examination showed evidence of bone destruction for at least 6 inches from the end (osteomyelitis). Periosteal bone formation was visible.

The consultant advised that the wound be opened immediately, to provide adequate drainage and to prevent upward spread of the infection, which would mean further loss of stump length. When the stump was laid open on 8 May 1945, it was found that the distal 1½ inches of the femur was a mass of small sequestra.

Some days later, the patient complained of dull, aching pain in the right arm. Roentgenographic examination on 28 May 1945 showed an area of bone destruction in the lower third of the shaft of the humerus, with evidence of osteomyelitis over a length of about 12 inches. Conservative treatment was instituted (immobilization, sulfathiazole, and penicillin), but sulfa drug therapy had to be discontinued on 10 June because of microscopic hematuria. Incision and drainage were performed on 23 June. The involved bone was necrotic and there was a great deal of purulent material in the area. *Bacillus aerogenes*, the same organism cultured from the stump, was cultured from this wound. Postoperative measures included 20,000 to 25,000 units of penicillin every 3 hours from 3 May to 22 July 1945. By 16 August, the wound in the arm was healed.

On 1 October 1945, the stump was revised. Recovery was satisfactory and a prosthesis was fitted on 22 December 1945. Thereafter, the patient did well.

Comment

The history just related is summarized from the complete report officially requested in this case, the management of which represented a gross deviation from sound surgical principles, as well as from the directives established by The Surgeon General. In submitting the report to the Consultant in Orthopedic Surgery, Surgeon General's Office, the service command consultant commented: "I am unable to explain why a man with the good judgment generally exhibited by Colonel ________ should have done a flap amputation in an infected case. It is possible that his faith in penicillin was too great."

Section I. Status of Returned Amputees

CASUALTIES FROM PEARL HARBOR

The report of Dr. LeRoy C. Abbott, civilian Consultant in Orthopedic Surgery to The Surgeon General, on the casualties he had examined at Letterman General Hospital, San Francisco, Calif., after they had been evacuated from Pearl Harbor in January 1942, concerned 16 amputations (in 70 patients), most of them through the leg (*12*). The recommended method of treatment was amputation followed by traction and the application of sulfanilamide to the wound. In nearly all instances, amputation had been done by the open circular technique as directed. The few cases in which primary closure of skin flaps was attempted were failures, though good results were achieved after prompt reamputation. Skin traction had been used correctly, and in some cases, plaster caps were added during transit to protect the wounds from trauma and hold the dressings in place.

It was perfectly evident from these observations, Dr. Abbott pointed out to the Subcommittee on Orthopedic Surgery, Committee on Surgery, National Research Council, at its 24 February 1942 meeting (*13*), that deep wounds should not be closed in evacuation hospitals; that the "guillotine" (open circular) type of amputation should be performed by the Kirk technique, which should be "taught in the schools with unanimity of purpose"; that the dosage of sulfanilamide by mouth at 4 grams for 4 days was adequate; and that "the drug, of course, should be applied locally," since, by its use, "many bad situations were undoubtedly saved." It was many months before the local application of the sulfonamides lost its glamour.

EVALUATION OF OVERSEAS MANAGEMENT

Factors that affected the condition of amputees on their arrival in the Zone of Interior included the initial site of the amputation, the efficiency of traction used during transportation, the length of time en route; and the presence or absence of soft-tissue infection and osteomyelitis. These factors also determined the type of treatment indicated in the Zone of Interior, including the necessity, in the majority of cases, for revision or reamputation. On the whole, in decided contrast to conditions in World War I, most casualties arrived in generally good condition, with their stumps open and free from infection. With few exceptions, they had traveled in comfort and without complications en route. When they were received in poor condition, it was generally because of associated conditions, particularly wounds of the abdomen and spine, or because of tropical and other diseases. At Walter Reed General Hospital, Washington, D.C.,

for instance, hepatitis was a fairly common complication, though the onset was sometimes delayed for many weeks after the patients' admission.

These comments are derived from the reports of some 20 chiefs of orthopedic sections in named general hospitals in the Zone of Interior who were asked, in December 1944, to report on the condition of returned amputees, with a breakdown by theaters. The survey was less comprehensive than had been hoped for because many records had already been retired or been transferred with patients and the data retained in the hospitals did not provide the desired information. Such records as were available, however, as these comments indicate, were usually unanimous in praise of the treatment the patients had received overseas.

The following adverse comments were made by some of the reporting hospitals:

1. The only real criticism at Lawson General Hospital, Atlanta, Ga., was that patients were still being received, and "not too infrequently," with their stumps closed primarily. Some of the wounds had healed, but about half of them were infected or a prosthesis could not be fitted without revision. Some patients objected to the additional surgery because they had been told that no more would be needed.

In some cases observed at Walter Reed General Hospital in which primary closure had been done, infection and chronic osteomyelitis in the terminal bone resulted in loss of length and a considerable delay before a satisfactory stump was achieved. At McCloskey General Hospital, Temple, Tex., about half of the primary closures either broke down or required prolonged convalescence before plastic revision of the stump could be undertaken.

2. Skin grafts had to be removed before stumps could be revised and prostheses fitted. Practically all surgeons not only found them useless but considered that they delayed rather than hastened final disposition.

3. There were a number of complaints about traction. It was omitted in only a few cases, chiefly prisoners of war (fig. 215), but the application was of varying efficiency in some cases, and in others, it had become ineffective during transportation. Some of the flexion deformities observed apparently had occurred under these circumstances.

4. In disarticulations of the major joints, particularly the knee joint, it was sometimes extremely difficult to obtain adequate healing before reamputation. The surgeons at McCloskey General Hospital suggested that, in many such cases, much time would be saved if supracondylar guillotine (open circular) amputation were used instead of disarticulation.

5. The skin was sometimes macerated, probably because too much petrolatum-impregnated gauze had been used.

6. Several patients were received at Percy Jones General Hospital, Battle Creek, Mich., whose amputations had been performed at the site of fractures, leaving fragments in situ that resulted in sequestra and delayed healing. This complication could have been avoided if the bone had been sectioned at the appropriate level when open circular amputation was done. In a number of other cases, the fibula was longer than the tibia; as a result, satisfactory traction was difficult to achieve and healing was delayed.

7. Patients were received at several hospitals with deep sinus tracts that had not been diagnosed.

8. A number of patients had decubitus ulcers and minor pressure sores caused by plaster casts, but in no instances were they serious. In 48 of 49 such cases observed at McCloskey General Hospital, the patients were received from the Pacific and had been a very long time in transit.

9. Below-elbow amputations were sometimes immobilized by plaster casts or traction with the elbow in complete extension. Prolonged physical therapy was required, and sometimes surgical correction, to obtain sufficient flexion of the limb for a prosthesis to be used effectively.

10. At Walter Reed General Hospital, the comment was made that amputees had lost time in hospitals not authorized to care for them, probably because of transportation problems. In a letter to Brig. Gen. Fred W. Rankin, Chief Consultant in Surgery, Surgeon General's Office, on 24 January 1945, Lt. Col. John J. Loutzenheiser, MC, Consultant in Orthopedic Surgery, Ninth Service Command, commented that many amputees in the Southwest Pacific Area had been similarly held, sometimes for 3 months or longer (*14*). He could understand that shipping had been tied up for the Leyte invasion, but he believed that a proper system of priorities could have brought these patients home much sooner. In fact, air evacuation had brought back many others with far lower priorities in terms of surgical needs.

11. In this same communication, Colonel Loutzenheiser related the histories of two patients seen at Letterman General Hospital, whose treatment had been entirely incorrect. Both had been wounded at Peleliu in the lower leg, and both had lost their legs from gas gangrene. Their wounds had not been debrided, but had simply been dusted with sulfanilamide and dressed. They were evacuated to the Admiralty Islands next day. Both arrived somewhat feverish and in some discomfort from their wounds, but not in acute pain. Again, they were kept overnight. Next day, they were flown to the Solomon Islands. That night, both felt ill and complained of increasing pain and discomfort in their wounds. When they were examined next day (72 hours after wounding), one in the morning and one later in the day, for the first time since the postwounding dressing had been applied, both were found to have gas bacillus infections, in one instance so severe that disarticulation of the hip was necessary after other surgical attempts to halt the infection had failed.

Colonel Loutzenheiser thought that it was then too late in the war for such surgical catastrophes to be occurring. Both of these cases emphasized the necessity for debridement within the accepted safe interval after wounding. Air evacuation must be conceived of in the same terms as any other system of evacuation—how long is it going to take to deliver the patient to a hospital for the completion of his surgical needs? He must receive the necessary care at the first stop, as if it were to be the last stop.

The complaints that have been mentioned, it must be emphasized, affected only a relatively small number of patients. At Walter Reed General Hospital, on 26 December 1944, it was reported that, of 469 amputees then in the amputation center, only 12 had been received in unsatisfactory condition (seven of 236 from the European theater, five of 233 from the Mediterranean theater). The only secondary hemorrhage reported in this investigation occurred in this group, from the European theater.

Of 877 amputees in the center at Percy Jones General Hospital on 2 January 1945, about 85 percent had arrived in good condition as far as their stumps were concerned. The other 15 percent were not in optimum condition, but chiefly because of associated wounds and other complications, not as the result of inadequate orthopedic care. Most of the men had traveled comfortably, and the only really serious complaint came from a man who, because of weather conditions, had been taken to an airport in England eight times before his plane was finally able to take off.

SUMMARY AND CONCLUSIONS

Examination of the data secured by the investigation of the status of returned amputees carried out in December 1944 produced the following comments from the Surgeon General's Office (*15*):

1. Skin traction, effectively applied, as it was in most cases studied, is the best method for transportation. Any form of elastic traction tends to become loose. If elastic traction is used, it requires constant attention, and responsible persons should be put in charge of it in transit.

2. Below-knee stumps should be put up in skin traction with the knee in full extension. Below-elbow stumps should have the elbow flexed at a right angle.

3. The cast-and-banjo type of traction is effective for ambulatory patients but not so effective as the weight-and-pulley method of bed treatment, which should be continued while the amputee is awaiting transportation and, whenever possible, during transit also.

4. Prolonged skin traction is preferred by all amputation centers to early closure of the stump. The maximum effect of skin traction should be obtained before secondary surgery is undertaken. This policy does not preclude preservation of short flaps of good skin at the site of amputation if early spontaneous healing can be achieved.

5. Skin grafting is also unpopular in amputation centers. It is justified only after maximum healing has been obtained by traction and is indicated only in cases in which it is clearly necessary before revision of the stump or in cases in which prompt evacuation is not possible. In no instance should skin for grafting be taken from the amputated extremity.[1]

6. Prosthetic requirements are best determined at amputation centers. Surgeons overseas should, therefore, advise all patients that additional surgery will probably be necessary in the United States. When they are told that no other operations will be required, it is often difficult to secure their concurrence when revision or reamputation proves necessary.

Section II. Training and Rehabilitation of Amputees

GENERAL CONSIDERATIONS

The Army amputation program included, in addition to surgery and the provision of prostheses fitted to individual needs, the training and rehabilitation of the amputee, and, less tangibly, the maintenance of his morale. The task was both physical and psychologic. Often, the actual loss of the limb was not so much a handicap to the casualty as was his reaction

[1] This is such an important, and at the same time such an obvious, consideration, it is odd that it was found necessary to emphasize it.—M. C.

to the amputation. The best results were achieved (1) when the patient understood, before the amputation, why it was inevitable and (2) when retraining was begun immediately after operation and was continued until the man could be restored to society as a productive member thereof. Progress was always faster if training was conducted with other patients who had undergone the same type of amputation. Also, the simpler the prosthesis, the better.

With lower-extremity amputations, retraining was not too difficult in most cases. An upper-extremity amputation was a different matter, and amputations above the elbow offered particularly serious problems. No prostheses existed, and none were developed during the war, that could compensate adequately for the loss of movement of the elbow, of pronation and supination of the forearm, and of the intricate and multiple capabilities of the hands and fingers.

Training both before and after the prosthesis was fitted was carried out by personnel of the Physical Therapy and Occupational Therapy Sections, who worked under the direction of the chiefs or other personnel of the amputation centers.

Throughout the program, it was recognized as highly desirable that amputees be used for instructional purposes in the various amputation centers, as well as in prosthetic shops (p. 885). The employment of civil ian amputees, including former military personnel, was also recognized as desirable. Unfortunately, not a great many amputees were desirous of remaining in service in any capacity after they had been fitted with their prostheses and had attained maximum improvement. They would have been a great stimulus to morale, as was evident at the amputation center at Bushnell General Hospital, Brigham City, Utah. Here the assistant chief of the service was a leg-amputee. Three other leg-amputees and two arm-amputees, all but one ex-servicemen, were employed as civilian instructors. A bilateral arm-amputee, a civilian, conducted the upper-extremity program and was a powerful factor in fostering morale as well as in vocational training.

COMPONENTS OF TRAINING

Physical therapy.—Throughout the program, emphasis was on the coordination of surgical and physical therapy (*16*). Technical Bulletin 122, published in December 1944 and entitled "Physical Therapy for Amputees" (*17*), covered bandaging of stumps, therapeutic exercise, massage, instructions for walking, exercises, and achievement tests. Massage was reserved for selected patients and was given with precautions, beginning with the certainty that latent infection was not present. Technical Manual 8–293, "Physical Therapy for Lower-Extremity Amputees," which was published in June 1946, was based on the total experience with amputations in

World War II (*18*). Film Strip 8–85, "Physical Therapy in the Treatment of Amputations," covered massage, exercises, and bandaging.

Upper-extremity amputees became the responsibility of the occupational therapist as soon as the immediate need for physical therapy was past. The physical therapist continued to work with the lower-extremity amputee, to improve his ability to walk, climb stairs, and engage in other activities. It was of prime importance for her to analyze the gait of each amputee. If he limped, the cause must be determined—weak musculature, a painful stump, or a contracture—and it must be corrected.

Occupational therapy.—The upper-extremity amputee was not limited to activities carried out with the intact hand. His use of a hook, vise, or clamp of some sort greatly increased his range of activities. Three approaches were possible:

1. If it was feasible, as it was in amputations of the middle or lower third of the forearm, the amputee was taught to use his prosthesis as if it were a normal limb.
2. If the amputation was above the elbow, he was trained to use the prosthesis as an aid to the intact hand.
3. If he had undergone high upper-arm amputation or disarticulation at the shoulder, he was taught to increase the range of activities of the intact hand; if a prosthesis was worn, not too much could be expected from it.

According to the 1945 report of the Walter Reed General Hospital Amputation Center, much of the occupational therapy there, and perhaps all of it, could be classed as diversional. On the other hand, few patients attended the classes who did not also derive some therapeutic benefit from them. One of these benefits was that it "opened the eyes of many patients to aptitudes they did not realize they had and helped them to choose careers." The self-reliance the amputees developed in these classes and contacts was an invaluable asset to men in their condition.

Since amputees nad difficult problems of adjustment, they were often inclined to be critical of their treatment and their prostheses. Certain aspects of the occupational therapy program seemed particularly useful in overcoming this difficulty. One such project was driving a car, which was a perfectly practical occupation for amputees if their cars were fitted with special controls. Progress was more rapid if another amputee served as instructor.

Horseback riding was a phase of the program that had no tangible benefits but that was useful in improving balance, providing healthful exercise, and inspiring the amputee with confidence in his ability to do whatever normal people could do.

Reconditioning.—ASF (Army Service Forces) Circular No. 298, issued on 4 August 1945, was an excellent statement of the reconditioning program for amputees (*19*). It covered the following points:

1. Basic principles, with references to the specific directives and other publications from which the total concept of reconditioning could be secured. Provision was made for a reevaluation of the patient's future in terms of his loss of limb. The importance of

his cooperation in the program was stressed.

2. Physical reconditioning. This was to be based on the programs outlined in War Department Technical Bulletin 10, published in February 1944 (*16*); Technical Manual 8–292, published in December 1944 (*20*); and ASF Circular No. 298, published in August 1945 (*19*). All material was modified to fit the needs of the individual patient.

3. Instruction in the use of prostheses. Guidance and help were given, but the patient was made to understand that it would be chiefly by his own efforts that he would learn to use his appliance effectively.

4. Instruction in everyday "living skills," with particular reference to personal hygiene, dressing and undressing, traveling, and other activities of daily life.

5. Educational and vocational guidance. This phase of the program was definitely related to the patient's mental and emotional orientation.

6. Recreation. This phase of the program was based on Technical Manuals 8–290 (*21*), 8–291 (*22*), and 8–292 (*20*). A great deal of attention was given to training in leisure-time activities.

ASF Circular No. 298 (*19*) went into the details of the various programs just outlined and provided daily schedules for amputees in all stages of reconditioning.

CONTRIBUTIONS OF CIVILIAN AND MILITARY AMPUTEES

A number of civilian amputees who had overcome their own handicaps and often had become highly proficient in the use of their prostheses offered their services to the Army, to demonstrate to service amputees what they, too, could expect to accomplish. Their proposals were in line with The Surgeon General's emphasis on training of amputees by amputees, and their offers were gladly accepted. Many of the arrangements for their visits were made locally, which was considerably less complicated than having them made under the auspices of the Surgeon General's Office. The civilians were referred to the commanding officers of the centers to be visited, so that the concepts and techniques they proposed to demonstrate should dovetail with the official programs.

Among the civilian amputees who contributed their services on a national scale were the following:

Mr. Walter Bura, a skilled engineer who had lost a leg above the knee in a diving accident, when he was shot out of a cannon into a pool, in 1941. He had developed a near-normal walking technique and could engage in such activities as running, bicycling, swimming, and even flying. A colored moving picture, "The Sky Is the Limit," produced at Walter Reed General Hospital Amputation Center, demonstrated his ability with an above-knee prosthesis.

Mr. Bura served as a civilian consultant to The Surgeon General and was the key figure in the discussions of walking technique at the 2-week conference held on this subject at Walter Reed General Hospital, Forest Glen Section, in October 1945 (*23*). The following month, he was made head of a similar program in the Veterans' Administration (*24*). Important contributions were made to this conference in connection with muscle testing and training by Mr. and Mrs. O. Kendall, of the Physical Therapy Department, Children's Hospital School, Baltimore, Md.[3]

[3] Mr. and Mrs. Kendall made other visits to the amputation center at Walter Reed General Hospital and also made important contributions to Technical Manual 8–293 (*18*) and to other publications concerning amputees and their reconditioning.

Mr. Harold Carlson, a civilian who had lost both arms above the elbow and who had become extremely proficient in the use of prostheses similar to those provided by the Army. As civilian consultant to The Surgeon General, he visited all the amputation centers in connection with the retraining of arm-amputees. In September 1945, Mr. Carlson and five World War II amputees who had lost both arms above the elbow were sent to the Regional Hospital at Pasadena, Calif., to be fitted with prostheses then under development in the research program at the Northrop Aircraft Corp. in Los Angeles, Calif. (p. 900).

Mr. Charles M. Kerr, who had lost a leg above the knee in childhood, was an extremely proficient athlete in various fields. He visited all the amputation centers under the auspices of the American National Red Cross, for which he served as Amputee Consultant from 4 December 1944 to 31 May 1946.

Mr. Charles McGonegal, a bilateral forearm amputee of World War I, who had trained himself to use hooks with great proficiency, visited each of the amputation centers several times, under the auspices of The American Legion, of which he was national field secretary (*25*, *26*). Mr. McGonegal further contributed to the amputation program by serving as the subject of the first training film for amputees, entitled "Meet McGonegal" (Misc. Film 956). An article in *Hygeia* for June 1944, "McGonegal's Hands," described the extraordinary abilities of this bilateral arm-amputee and his complete readjustment to life (*27*).

"Meet McGonegal" was the inspiration for another film, "The Diary of a Sergeant" (Misc. Film 1129), which relates the experience of Sgt. Harold Russell, who lost both hands early in the war in a training accident. It portrays his early mental depression, the inspiration he received from "Meet McGonegal," his progress in physical and mental rehabilitation, and his ultimate proficiency in the use of prostheses. Within 4 months after his retraining began, Sergeant Russell was able to carry on most of his normal daily activities.[3]

Lt. Bert Shepard, who lost his leg below the knee in May 1944, after being shot down in aerial combat and imprisoned in Germany, resumed his professional baseball career in the summer of 1945, 3 days after receiving his prosthesis. He reentered the service at the request of The Surgeon General, to participate in the amputation program (*28*). His athletic skills, which included football and running as well as baseball, made him an excellent test subject for the various prostheses then undergoing trials, and his visits to all the amputation centers were a stimulus to the morale of the amputees. Lieutenant Shepard was the subject of a film depicting his skill in sports entitled "Half a Chance."[4]

OTHER TRAINING AIDS

In addition to the films already mentioned, the Army produced a training film entitled "Swinging into Step" (TF 802083), which depicted the overall amputation program, including surgical care, limb fitting, physical therapy, occupational therapy, reconditioning, various forms of recreation, and other aspects of rehabilitation before the amputees were

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[3] At the present time (1970), Mr. Russell is Chairman of the President's Committee on Employment of the Handicapped.

[4] On 9 January 1945, two servicemen who had suffered amputations and been fitted with prostheses at Walter Reed General Hospital (Cpl. Leland Grohman and S. Sgt. Fernand LeClaire) reported for temporary duty in the European theater, to demonstrate their abilities and to explain the prostheses they were using (*29*). These demonstrations were so successful that additional amputees were sent to the theater for the same purpose. It was evident that early visits to theaters of operations by amputees who had been rehabilitated would be a decidedly worthwhile part of any future amputation program.

separated from service. The film opened with a showing of amputees on a hospital ship returning to the United States and provided replies for the questions they asked about their hospital treatment and convalescence. Both civilian and service amputees were used to demonstrate the abilities of men who had been rehabilitated and who were holding jobs in all walks of life. The film was approved for public showing and was of considerable interest to civilians as well as to military personnel.

A pamphlet prepared at Bushnell General Hospital, "Helpful Hints to Those Who Have Lost Limbs," was published on 15 May 1944 and proved so useful that it was distributed by the amputees who went to the European theater in January 1945 (*30*).

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CHAPTER XXXII

Amputations of the Upper Extremity

Leonard T. Peterson, M.D.

GENERAL CONSIDERATIONS

Amputations of the upper extremity[1] comprised approximately 20 percent of the approximately 15,000 such operations in U.S. Army personnel during World War II (p. 865). Amputations of the fingers and hand are considered in detail in the volume of this historical series dealing with hand surgery (*1*) and are, therefore, omitted from this chapter. Their importance, however, warrants brief mention here.

Because of the multiplicity of functions performed by the arm and hand, functional restoration of the amputated member by prosthetic replacement had, as a rule, only a limited degree of success, even under the most propitious circumstances. Instruction in the correct use of prostheses, particularly those used after amputations above the elbow, was, therefore, of fundamental importance in the management of the amputee. Estimates from World War I, as well as independent civilian surveys, indicated that from 60 to 80 percent of patients who had undergone amputation at various levels of the upper extremity soon discarded their prostheses. In an effort to counteract this tendency in World War II, great stress was laid on the training phases of the program at the various amputation centers. Routine occupational therapy, which is inherently artificial, lacked essential stimulus and also lacked the force of example. Efforts were, therefore, made to secure instructors who were themselves amputees, particularly those who had sustained the loss of their limbs in service. The number of such personnel was limited, but through their devoted work, and based on their personal example, a useful program was developed that included instruction and practice in what might be termed "a way of life."

Section I. Disarticulation at the Wrist

GENERAL CONSIDERATIONS

Disarticulation at the wrist had two definite advantages over amputation through the forearm:

1. The prosthesis used did not require either an elbow joint or a cuff

[1] Unless otherwise indicated, the material in this chapter is derived from reports prepared by Dr. (formerly Lt. Col., MC) Ernest E. Myers, Dr. (formerly Lt. Col., MC) Donald B. Slocum, and Dr. (formerly Maj., MC) Harold W. Woughter.

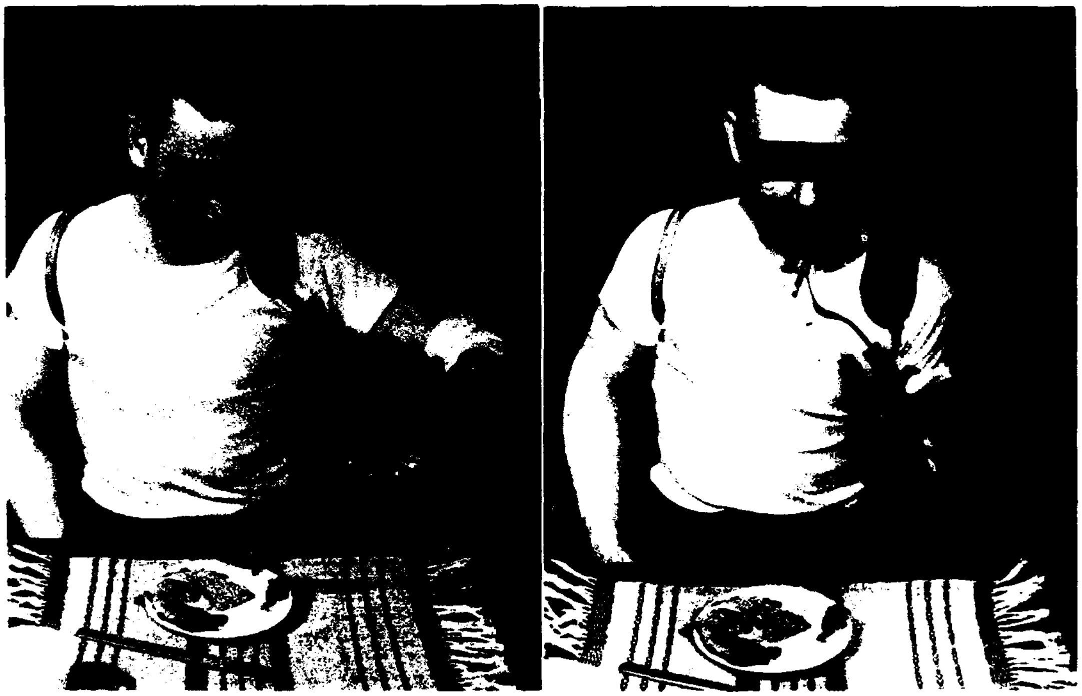

FIGURE 216.—Demonstration of use of prosthesis with hook attached after disarticulation of left wrist.

above the elbow, either of which could limit flexion and cause discomfort in the antecubital space.

2. Pronation and supination of the arm were both retained, which made it possible to use a prosthesis with greater dexterity (fig. 216).

There were, however, three equally definite objections to this procedure:

1. The classical objection that the prosthesis was too long. Since the artificial hand rested in such a position that the tip of the thumb opposed the tip of the index finger, this juncture was taken as the distal point of measurement. Observations on a large number of amputees showed that there was no increase in the length of the prosthesis when a short hook was used and an average increase of only three-fourths of an inch when the hand was used, a discrepancy so slight as to be scarcely apparent. From the esthetic standpoint, therefore, the increase in length could not be considered objectionable, and it was hoped that it would be eliminated with further prosthetic developments.

2. Failure of rotation of the forearm to be transmitted to the prosthesis. While this failure was undoubtedly true in some stumps, others were observed in which a fair amount of active rotation present in the forearm was forcefully demonstrated in the prosthesis.

3. Avascularity of the stump. When this condition was present, it could be explained in two ways, poor selection of cases and failure to

provide suitable integument for coverage of the stump. When skin was drawn tightly over the end of the stump, particularly in the region of the styloid processes, the stump was avascular and painful. It was noted, however, that when a prosthesis was applied, there was considerable improvement in the appearance of the skin and the cicatrix.

The ideal stump after disarticulation of the wrist was oval, soft, well padded, and nontender. The scar, which was located just distal to the styloid processes, was terminal, mobile, and linear. The anterior flap covered two-thirds of the stump. Palmar skin in this stump protected the anterior lip of the radius in much the same fashion that it does when the normal wrist is extended. The radius and ulna retained their normal configuration. The intact styloids were covered with loose, well-padded skin, and their prominences allowed the prosthesis to grip the stump just as the Syme prosthesis grips the tibia and fibula at the ankle joint. Pronation and supination were within normal range.

Disarticulation at the wrist was undertaken only when three criteria could be met:

1. The radius and ulna were intact.
2. The distal radio-ulnar joint with its supporting triangular ligament was also intact.
3. It would be possible to cover the stump with well-vascularized skin, with normal sensation and with a thick layer of subcutaneous fat.

TECHNIQUE

As in all amputations, the proper development of the skin flap was a primary consideration in disarticulation of the wrist. In the procedure of choice, the flap was developed simply by modifying the elliptical palmar incision by the creation of anterior and posterior flaps of unequal length (fig. 217). The stump that resulted from this technique had a neat, tailored appearance (fig. 218) and fitted satisfactorily in the prosthesis.

The palmar skin flap was created by using an incision that began at a point on the radial aspect of the wrist joint, at the junction of the anterior two-thirds of the anteroposterior diameter with the posterior third, one-half of an inch distal to the joint line, to allow for retraction of the skin. This incision passed distally and palmarward to the level of the carpometacarpal joint of the thumb. It then crossed the palm to the fifth metacarpal hamate joint, ending at a point one-half of an inch below the midpoint of the ulna. The incision for the dorsal flap curved gently backward distally for one-half of an inch, crossed the dorsum of the wrist transversely, and then curved upward to meet the starting point of the palmar flap at its radial aspect.

After the configuration of the flap was established, the soft tissues connecting the carpus with the proximal structure were severed. Operation then continued in the following steps:

FIGURE 217.—Line of incision for disarticulation at wrist. (Left) Radial view. (Center) Ulnar view. (Right) Palmar view.

1. The radial and ulnar arteries were isolated, to prevent their retraction up into the forearm, and were sectioned and ligated.
2. The median and ulnar nerves and the superficial branches of the radial nerve were pulled downward by gentle traction, sectioned transversely, and then allowed to retract.
3. Dissection was continued from the radial aspect of the wrist, the ligaments and tendons being sectioned at their highest levels. In the approach to the ulnar aspect, care was taken to preserve the triangular ligament and the underlying radio-ulnar joint. The cartilage was usually removed from the distal end of the radius. If the radial and ulnar styloid processes were unduly prominent, they were rounded. If the curve of the wrist was unusually marked, the proximal carpal row was sectioned, so that the end of the bony stump would pass in a straight line between the styloids.
4. After hemostasis was secured, the skin flaps were brought together without tension by interrupted sutures, and a compression dressing was applied.

PROSTHESES

Whether or not a disarticulation of the wrist could be classified as successful depended chiefly upon whether a satisfactory prosthesis could be fitted. The first fitting was usually undertaken about 6 weeks after amputation, an interval sufficient for healing of the wound and shrinkage of the stump (fig. 219):

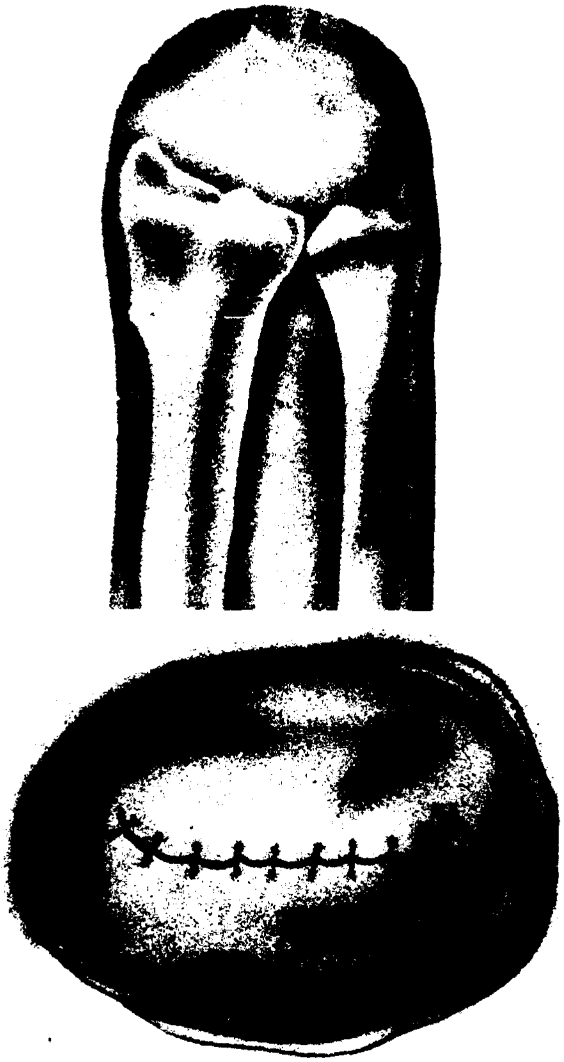

FIGURE 218.—Stump after disarticulation at wrist.
(Top) End view. (Bottom) Dorsal view.

The socket was made by molding wet leather over a positive impression of the stump. The leather was fixed by stitching it while it was still wet, after which the socket was cured in a drying oven. A U-shaped reinforcing stainless steel band was shaped in the usual mid anterior and mid posterior positions, and a nut was welded to the distal end in a position to mount the hand or hook. The nut had the standard diameter of one-half of an inch, with 27 threads per inch. The mold was removed from the positive plaster image by splitting the leather on the radial side to a point 1½ inches from the distal end of the socket, at which point the leather was later trimmed to form a lacer. The socket was riveted onto the steel frame.

Early sockets, which extended to within one-half of an inch of the insertion of the biceps tendon, had two disadvantages, (1) that when they were worn, the soft tissues of the antecubital space were pinched, and (2) that they did not permit the maximum range of pronation and supination. When the socket was shortened to about 7 inches, these objections were eliminated, but the pull cord from the shoulder harness bowstringed across the elbow when the arm was flexed.

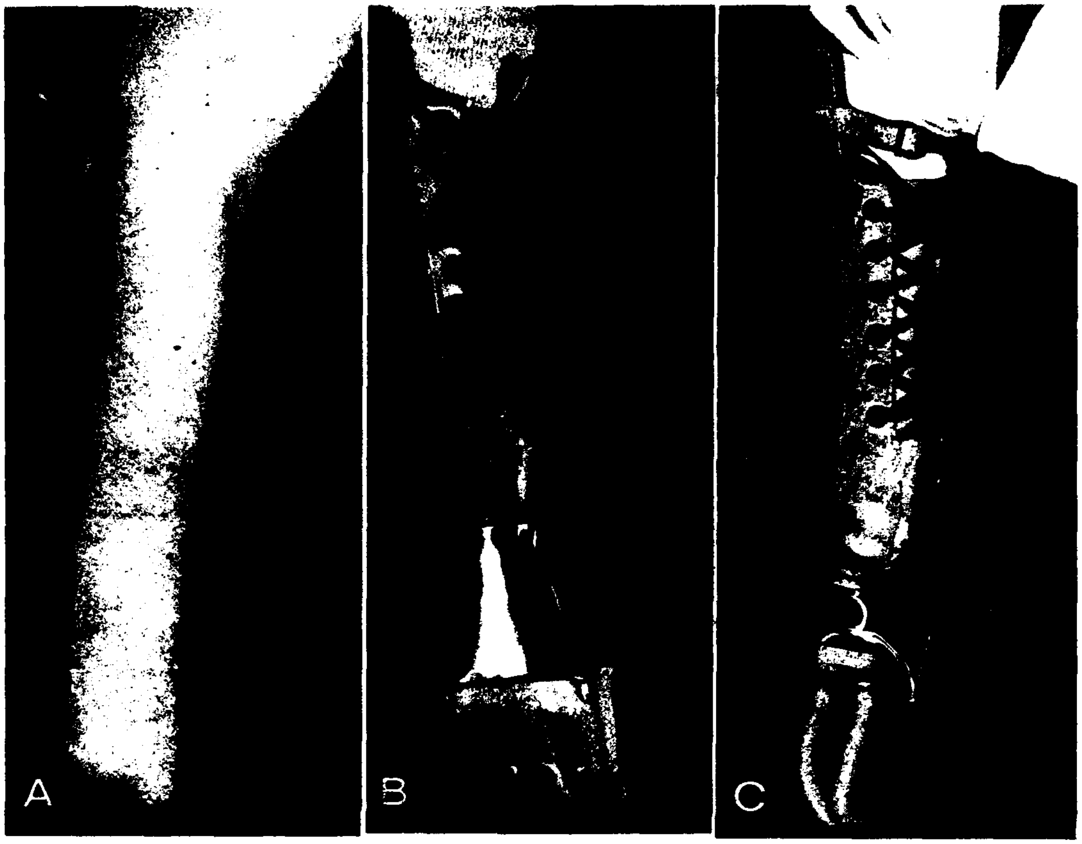

FIGURE 219.—*Disarticulation at wrist. A. Resulting stump. B. Prosthesis with hand attached. C. Same, with hook attached.*

In its final form, depending upon the length of the arm, the prosthesis extended from 6 to 7½ inches above the styloid process of the radius, and on the medial aspect extended to a point about 2 inches distal to the medial epicondyle. A loop was incorporated in this extension for the reception of the pull cord.

The prosthesis was fitted with the elbow in 90 degrees of flexion and with the forearm in mid rotation. The shoulder harness was fitted with the conventional loop about the opposite shoulder. A cuff incorporated on the shoulder on the prosthetic side supported the cord and prevented it from bowstringing on that shoulder. The pull cord at first was made of conventional catgut or leather. Later, it was replaced by the Northrop cable (p. 948), which gave better control.

Section II. Amputations of the Forearm

SITE OF ELECTION

Amputation of the forearm at any bone level near the wrist that disturbed the integrity of the distal radio-ulnar joint was undesirable because (1) postoperative rotation was limited and was often painful and (2) the resulting lateral pressure of the radius on the ulna was also often

painful. Moreover, the distal expansions of the radius and ulna that grip the prosthesis in a disarticulation were absent in amputation at this level.

When a patient who had undergone amputation above the wrist was fitted with a prosthesis, it was usually necessary that the appliance extend above the elbow and also usually necessary to utilize conventional hinge joints. As a result, all rotation was effectively eliminated. Still another objection to amputation in the distal end of the forearm was that the skin for coverage was usually obtained proximal to the transverse creases of the wrist, where the integument is unsuitable for coverage of a stump because it is avascular and lacks subcutaneous tissue.

Lower third.—The World War II experience with amputations through the lower third of the forearm duplicated the experience of World War I and the general civilian experience. They were practically always attended by certain disadvantages:

1. Circulation was poor because the layer of subcutaneous tissue in this area is thin and consists chiefly of tendons and fascia.
2. The skin that received its blood supply from this subcutaneous tissue was notably slow to heal, and the result was frequently a cold, cyanotic, tender stump.

In the World War II experience, as in previous military and civilian experience, even when the skin was perfectly satisfactory as coverage for the stump, the bone was often poorly padded and the stump was not particularly suitable for a prosthesis. Moreover, the additional length of the forearm provided by amputation at this level produced no increase of power over that provided by the stump resulting from amputation at the junction of the middle and lower third. This stump was also too long to accommodate the Northrop prosthesis, which allowed rotation of the stump.

Junction of middle and lower third.—Amputation at the junction of the middle and lower third of the forearm produced an ideal stump. Function was good because in this region the skin is tough, circulation is excellent, and there is adequate subcutaneous tissue to pad the bones. Also, there is more muscle and less tendon than at the more distal level. Pronation and supination could be maintained if motion was started early and if there was no synostosis between the radius and the ulna.

TECHNIQUE

General considerations.—The most important objective in amputation of the forearm at the junction of the middle and lower third was to secure a stump with a thin suture line, smooth covering, and no adhesions to underlying bone. Next in importance was the grouping of the muscles about the bone so as to form a good circumferential pad without additional bulk.

If these objectives were achieved, the stump was usually satisfactory.

The ideal scar was situated terminally, but it could extend in almost any direction and the stump would still be useful. Nonconventional types of scars were usually the result of plastic repair after open circular amputation.

Steps of the operation.—The technique used in amputations of the forearm was essentially that described by Col. (later Maj. Gen.) Norman T. Kirk, MC, which utilized a terminal suture line and rounded anterior and posterior flaps.

The operation could be performed with or without a tourniquet. The arm was placed in moderate flexion at the elbow, a position most convenient for the surgeon, and was held midway between pronation and supination. The skin flaps were so cut that their combined length was equal to the diameter of the arm at the level of the amputation. The incision was begun on the mid-lateral aspect of the forearm at this level, swung downward, and then carried conversely across the dorsum of the forearm to a point on the mid-medial aspect of the forearm at the level at which the bone was to be divided. The anterior flap was created by the same technique.

There was not general agreement as to how to handle fascia and muscle, the pattern of management being affected by three concepts of correct covering for the bone ends:

1. The bones should be covered by skin alone.
2. The bones should be covered by a layer of skin and a layer of fascia.
3. The bones should be covered by skin, muscle, and fascia. When this technique was used, fascial flaps were cut in a pattern similar to that of the skin flaps and the muscles were so sectioned that they fell at the level at which the bones were cut. The muscles were then sutured over the bones and the fascia over them.

Although a large number of *forearm amputations* were performed with skin coverage, skin-fascia coverage proved superior for a number of reasons: The bones were well padded. No prominent bone ends were present. The muscles were well grouped about the radius and ulna, so that there was no redundant or edematous tissue at the end of the stump. Wound healing was generally satisfactory.

In the Kirk technique, the bones were cut at right angles to the long axis of the arm as it was held in mid position. A periosteal cuff, measuring one-eighth of an inch, was then removed from each bone, care being taken not to strip the periosteum or to leave ragged tags to form a basis for future osteophyte formation. After section, the bones were smoothed with a file or rasp, and all bone dust was washed out of the wound with physiologic salt solution. An attempt was usually made to round the lateral aspects of the stump by beveling the cortex of the ulna on the medial aspect and of the radius on the lateral aspect. This technical refinement improved the contour of the bone and was especially desirable when adequate muscular covering could not be provided.

The median, ulnar, and radial nerves were isolated, drawn down into the wound, and so sectioned that they retracted to a well-protected position.

The arteries were isolated and ligated, and painstaking hemostasis was accomplished.

Closure of the skin wound was carried out after the flaps had been so tailored that perfect apposition could be secured. Any scar tissue in the flaps was excised. Slight tension of the suture line was desirable.

PROSTHESES

In amputations of the upper extremity, a permanent prosthesis could be fitted early for two reasons, (1) that relatively little shrinkage of the

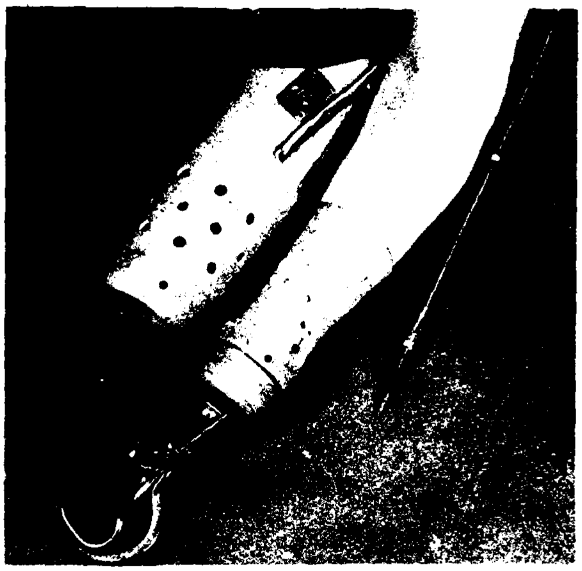

FIGURE 220.—Northrop rotary forearm prosthesis with double socket.

soft parts occurs in the stump and (2) that weight-bearing points do not have to be considered, as they must be in the lower extremity.

The action of most prostheses for the upper extremity depends upon normal shoulder motion. If the shoulder is fixed or paralyzed, the usefulness of the artificial limb is materially limited. When, however, there is a satisfactory stump and the shoulder motion is normal, a prosthesis has a wide range of usefulness even though function is less than optimum. The World War II experience bore out these generalizations.

Motion of the elbow was limited to flexion and extension. If the prosthesis ended below the elbow, these movements were accomplished by the normal elbow joint. If, however, it extended above the elbow, an artificial elbow joint was required.

In long forearm stumps, just as in amputations at the wrist joint, rotation of the forearm was preserved and could be utilized if there were no rigid hinged joints at the elbow. In shorter stumps below the elbow, rotation could be preserved only if a double socket (Northrop prosthesis, fig. 220) attached to the elbow was provided.

Flexion and extension of the wrist are not essential movements and they were not usually provided for in an artificial limb. In a normal intact wrist which had been fused in a good functional position, excellent function of the hand and fingers was usually possible, but the addition of flexion to a prosthesis usually complicated it far beyond any benefits that could be obtained thereby.

Simplicity in fitting was found to be of special importance in amputations of the forearm, and many patients could acquire satisfactory function with a semiflexible plastic socket that incorporated a hand or

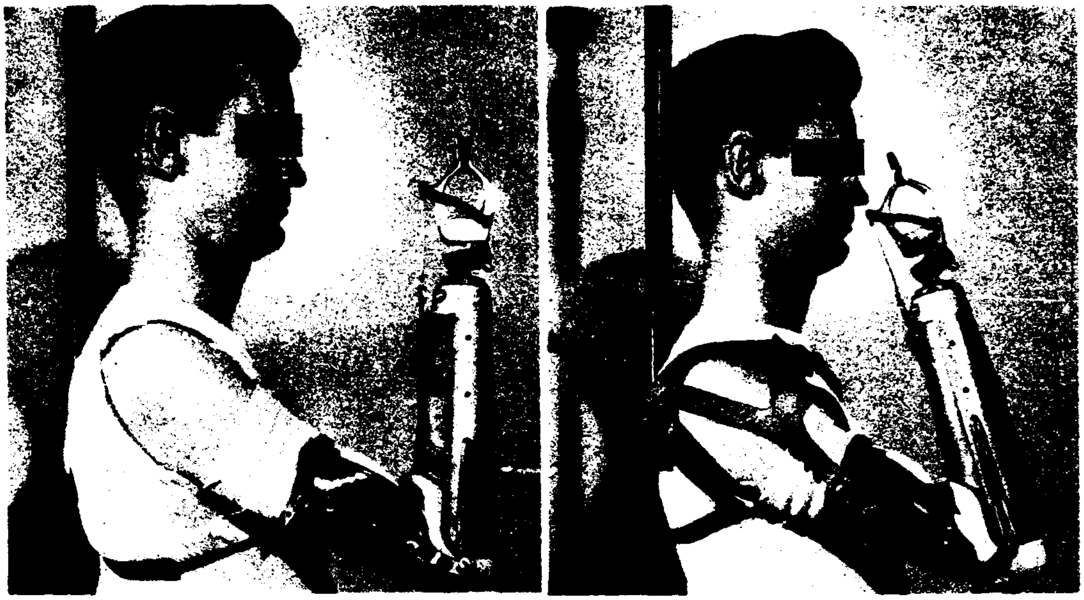

FIGURE 221.—Below-elbow prosthesis. (Left) With single-hinged joint. (Right) With double-hinged joint.

hook connection and was attached to the body by a simple harness and cord. Elbow joints were eliminated whenever possible. The amputee had greater flexibility and comfort without them.

Sockets.—A stump ending in the lower third of the forearm could not be fitted with a rotary wrist mechanism without the creation of a rather obvious discrepancy, amounting to as much as 1½ inches, in the length of the two limbs. The increase was the result of the considerable space occupied in the terminal portion of the prosthesis by the internal rotary mechanism. If the conventional prosthesis was worn, amputation at this level (lower third) had none of the advantages of disarticulation at the wrist, in which pronation and supination could be obtained. Instead, there was loss of the distal radio-ulnar joint and of the distal flares of the radius and ulna.

Sockets for below-elbow stumps were usually of leather or plastic. When plastic materials were used, the degree of hardness was controlled by various combinations. The socket was made over a plaster mold of the stump and was fastened to a metal frame with a standard wrist attachment. Hinged elbow joints were attached to the forearm socket, which was usually of the rigid closed type (fig. 221), and to the laced arm cuff.

A very short forearm stump was occasionally fitted as if a disarticulation at the elbow had been performed. On the other hand, even a short stump permitted useful control of the prosthesis. Since the attachment of the biceps tendon limited the length and fit of the upper border of the socket, this tendon was sometimes sectioned, to permit fitting of an ex-

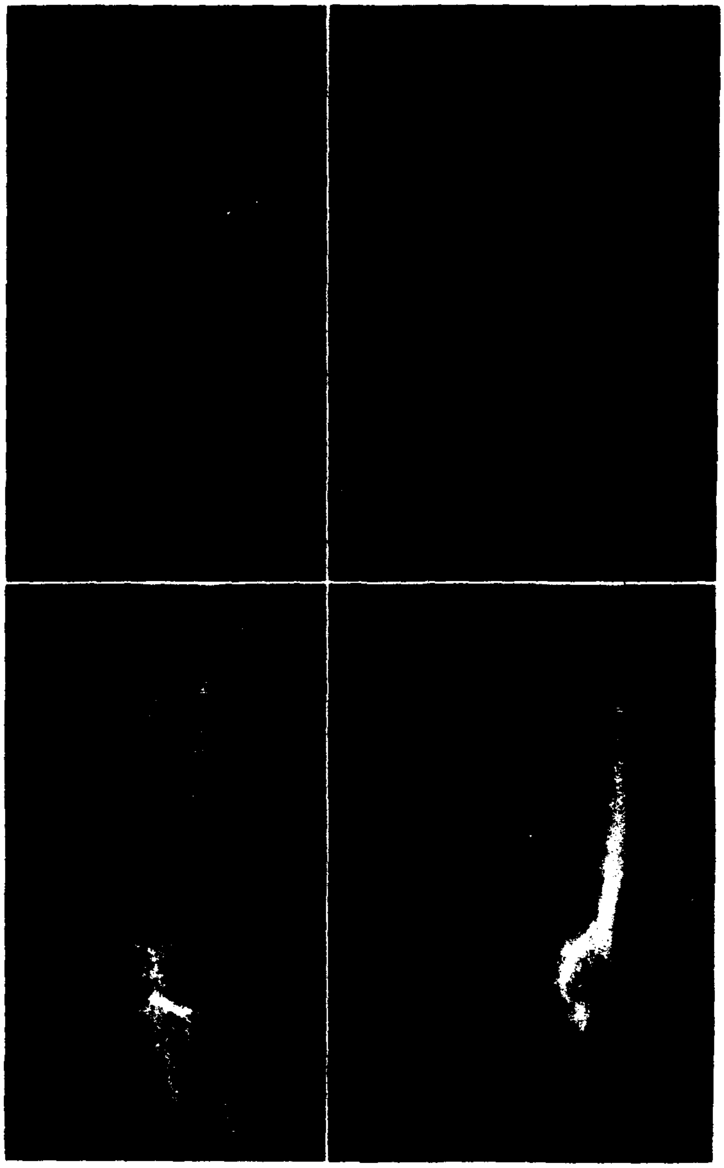

FIGURE 222.—Management of short left forearm stump. (Top) Anteroposterior and lateral roentgenograms, showing short stump with obstructing radius. (Bottom) Same, after removal of radius and insertion of biceps tendon in coronoid process of ulna.

tremely short stump. The brachialis muscle provided sufficient power for elbow flexion.

Elbow joint for below-elbow amputations.—In long forearm stumps, the elbow joint and arm cuff could be omitted entirely; only straps were necessary at the elbow. In short stumps, it was advantageous to use polycentric elbow joints that permitted a wide range of motion without the constriction often observed when a single hinge was used (fig. 221). It

was important to place the center of the lateral hinged joints of the artificial elbow at the axis of the normal joint; otherwise, the socket would bind the joint and restrict its motion.

An elbow in which flexion was seriously limited could not fully utilize a forearm prosthesis. By a special step-up arrangement at the elbow, however, the forearm could be made to traverse a much greater range of flexion than was possible in the elbow joint (fig. 222). A prosthesis of this kind was especially valuable in short below-elbow stumps. It eliminated the necessity for reamputation in cases in which, because of the limitation of motion, the stump would have been unsuitable for fitting a prosthesis.

Northrop rotary prosthesis for forearm stump.—An amputation through the middle third of the forearm left a stump with considerable rotary motion that was lost when a conventional socket and hinged elbow joints were used. This ability was preserved, however, when the double socket Northrop rotary prosthesis was used (fig. 220). The inner socket, which was constructed to fit the stump, rotated inside the outer socket, which was attached to the elbow. The hand (hook) was controlled by the stump socket, and the mechanism was so geared that a slight degree of rotation of the stump produced two or three times as much rotation of the hand. The rotary mechanism was of a freewheeling type; it moved easily by rotation of the forearm, but could be locked into any desired position.

Hands.—Most artificial arms were supplied with some sort of hand (fig. 223) which, however, had limited functional value. There were a number of reasons: In the construction of an artificial hand, only a few sources of power are available. The space for mechanical parts is limited. The weight of the device must be kept to a minimum. As a result of these handicaps, many types of artificial hands were of limited usefulness, were undesirably complicated, or were either too heavy or too fragile.

Flexion and extension could be provided for all the fingers of the artificial hand or only for the index and middle fingers. Often, the fourth and fifth fingers were allowed to remain rigid. In other models, these fingers were flexible without activation and could be set to any desired position. The thumb, preferably, was movable, so that its action could be synchronized with finger flexion, but it could also be fixed in opposition. In some hands, the thumb was neither rigid nor activated but was adjustable to certain selected positions by the normal hand as the specific work to be done might require.

One hand used in World War II had an aluminum palm and rubber fingers and thumb. The fingers and the opposing thumb could be actively flexed at the metacarpal phalangeal joints by action of the shoulder cord. When a small lever was preset, this action was free, or the hand could be locked at any desired position. Another hand, with very limited function, had a wooden palm and a spring type of finger and thumb that closed on spring action and was opened by active control (fig. 223D).

FIGURE 223.—Prostheses for upper extremity stumps. A. Forearm prosthesis with metal frame, leather socket, leather cuff, Dorrance hook, and bowdenite cable. B. Above-elbow prosthesis for short stump. Note shoulder cap. C. Wood hand with fixed fingers and movable thumb. D. Becker hand with flexible metal fingers that open actively and close by spring action; split (right) Dorrance hook. E. Miracle hand, with motion at all metacarpal phalangeal joints. This hand opens passively and is closed by cord activation.

Still another hand was made of metal with the fingers lined with sponge rubber. Hands made completely of wood either were entirely rigid or were flexible at the metacarpal phalangeal joints of the thumb (fig. 223C) or of all the digits.

Early in World War II, mechanical hands were unsatisfactory cosmetically, and the wearing of leather gloves over them made them only a little less conspicuous. Their appearance was improved during the war, and since then, an excellent functional hand, with good cosmetic covering, has been developed at the Army Prosthetic Research Laboratory at the Walter Reed Army Medical Center, Washington, D.C.

Hooks and working tools.—Hooks attached to prostheses (fig. 223) are conspicuous and objectionable cosmetically, but in World War II, as in civilian life, their functional value far outweighed this disadvantage and made it imperative that all amputees, especially those who had lost both upper extremities, be trained to use them.

The mechanical hook used was based on the pincer principle. Its two parts were hinged at the base and could be opened or closed by the cord attached about the shoulder on the normal side. The source of power was a shrug of the shoulder, just as for the artificial hand. The hook was usually closed by one or more rubber bands that encircled the pincers

near the base. The force of the closing action was controlled by the number and strength of these bands.

When the hook was closed, it could be used as a single or rigid instrument, which was not so useful as the articulated type and was, therefore, not usually used. The articulated hook was opened by voluntary action and closed involuntarily by a spring or rubber bands, or was opened by spring action and closed by voluntary action. Voluntary closing gave greater power and better control, but it left the hook open when it was not in use, which was not desirable.

The hook usually used had a side-pull through a small projecting lever to which a cord was attached. The catgut and leather cords originally used had poor mechanical efficiency and were replaced by bowdenite cables, composed of multiple strand wire encased in a flexible metal housing. A more desirable connection was the center-pull, in which the cord was concealed in the wrist connection. A mechanical hook could usually tolerate resistance of 2 to 8 pounds.

A wide variety of working tools were designed for use by amputees in industry, transportation, and household activities. Special bench tools included holders, pliers, hammers and saws, which could be attached to the prosthesis and separated from it easily and quickly. Devices for farming and gardening included attachments for implements and garden tools. For driving, a connection that looked like a ball was attached to the steering wheel and was controlled by a matching cup attached to the prosthesis; it was of the greatest importance that the prosthesis could be readily detached from the steering wheel. Other implements were provided for household and personal use.

Section III. Amputations Immediately Below the Elbow

GENERAL CONSIDERATIONS

It is well known that a much larger proportion of upper extremity amputees will wear prostheses when they have their own elbow joints than when the amputation has been above the elbow. The functional results with below-elbow amputations are always far better than those obtained after high amputations. For this reason, no effort was spared in World War II to save the elbow joint. Amputation above the elbow, however, was considered to be indicated when the elbow joint was functionally useless.

TECHNIQUE

Increasing the range of flexion.—Amputees with short forearm stumps, with 2 to 2½ inches of ulna in situ and an even shorter radius, many times had a full range of motion at the elbow. Nevertheless, attempts to fit these

stumps and utilize such elbow function as was available often failed. On flexion, the insertion of the biceps tended to push the stump from the socket, or the redundant soft tissue tended to become pinched in the antecubital space. In either event, the range of motion was restricted. When there was an excessive amount of soft tissue about the elbow, the situation could be corrected by dissecting away the remaining muscles of the forearm, which were useless, leaving the radius and ulna, with the upper arm muscles attached and covered by fascia and skin, to be used for leverage.

In some short forearm stumps, because of upward and medial deviation, the radius tended to overlap the ulna (fig. 222) and to interfere with the full range of elbow motion. The relation of the radial head to the capitulum was thus so changed that the head acted as a wedge that limited the arc of flexion. In addition, its abnormal position destroyed the ability of the short forearm stump to act as a lever.

In such instances, the remainder of the radius was removed and the tendinous insertion of the biceps was transplanted into the coronoid process of the ulna or was transected at its insertion and allowed to retract. The division of the biceps tendon did not seriously interfere with the flexion of the forearm stump, which was accomplished by the brachialis muscle.

Other procedures.—Various plastic procedures were also used to restore elbow motion when the injury necessitating the amputation had occurred near the joint. They included removal of contracting scars or adhesions, tendon lengthening or transfer, capsulotomy, and arthroplasty.

Bone lengthening operations were done in occasional cases in which good elbow motion was present but the forearm was too short for use of the multiplying-action prosthesis. The bone graft was covered with redundant skin and soft tissue available at the end of the stump, or, if sufficient tissue was not available in this location, a skin graft was applied to the end of the stump before the graft was inserted.

The fibula was usually used at the donor bone. The graft was driven into the medullary canal of the ulna (fig. 224) and fitted so snugly that, as a rule, transfixion was not necessary. Before the graft was inserted, multiple small drill holes were placed in it, to facilitate vascularization and to fix overlying soft tissue, so as to lessen the hazard of rotation on the graft.

Three lessons were learned from the experience with bone lengthening in short forearm stumps:

1. The fibular graft should be just long enough to activate a multiplying-action prosthesis, and its total length should not exceed 3 inches.
2. The skin tube should be just long enough to cover the bone graft.
3. If there is any doubt concerning the nutrition of the skin tube, it should be reattached to the chest wall and left there until the bone graft is thought to be secure.

PROSTHESES

It was soon found that a forearm stump less than 2 inches distal to

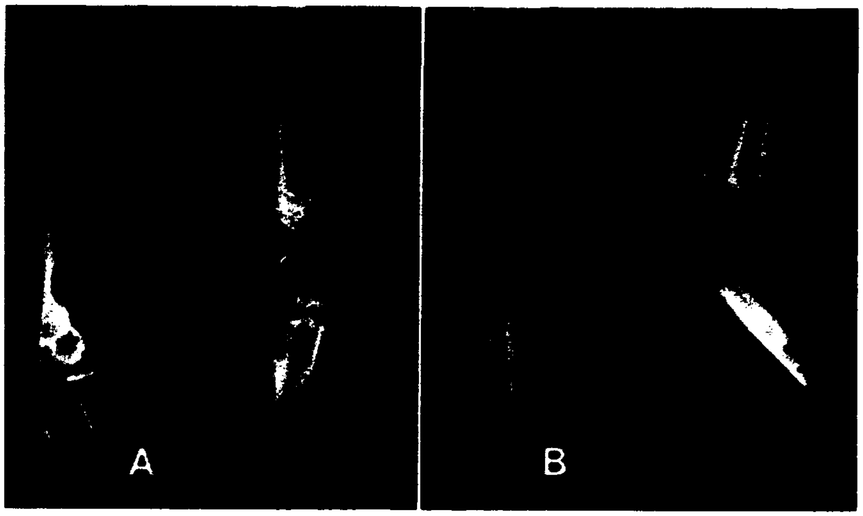

FIGURE 224.—Management of short right forearm stump, inadequate for activation of prosthesis. A. Lateral and anteroposterior roentgenograms, showing short bone length. B. Anteroposterior and lateral roentgenograms, showing stump lengthened 1 inch by fibular bone graft. Note multiple drill holes in graft.

the insertion of the biceps would not motivate a single-action elbow joint prosthesis beyond 90 degrees of flexion. This problem was solved by the development of a multiple-action elbow joint (fig. 225) with which the stump moved in a ratio of 1 : 1.5 in relation to the forearm segment of the prosthesis. Though some lifting power was sacrificed, the loss was compensated for by increase in the range of motion and in smoothness of action.

The elbow-joint prosthesis consisted of three components, the socket, the arm lacer, and the forearm unit; they were jointed at the elbow by the three bars of the multiple action elbow joint. The socket was made from a cast which was molded about 1½ inches above the olecranon while the stump was held in slight flexion. Gauze impregnated with a contact pressure plastic resin (Bakelite BRS 16631) was applied to the cast, which was then cured. When the proper precautions had been taken to secure rigidity and an accurate fit, and to keep the weight light (the average weight was 21 ounces), the resulting socket was excellent. The forearm unit, also of gauze and plastic, was fabricated over standard tapered forms of sheet aluminum. A dural wrist connection of the Hosmer or Dorrance type was incorporated into the distal end.

FIGURE 225.—Management of short right forearm stump. A. Stump 5 weeks after circular amputation. Note indentation and contraction of skin. B. Lateral and anteroposterior roentgenograms, showing minimal length of forearm suitable for use of multiple-action elbow joint prosthesis. C. Forearm stump in maximum flexion after revision. D. Multiple-action prosthesis shown in full flexion. Note position of stump versus prosthesis. E. Same, with shoulder in abduction and external rotation.

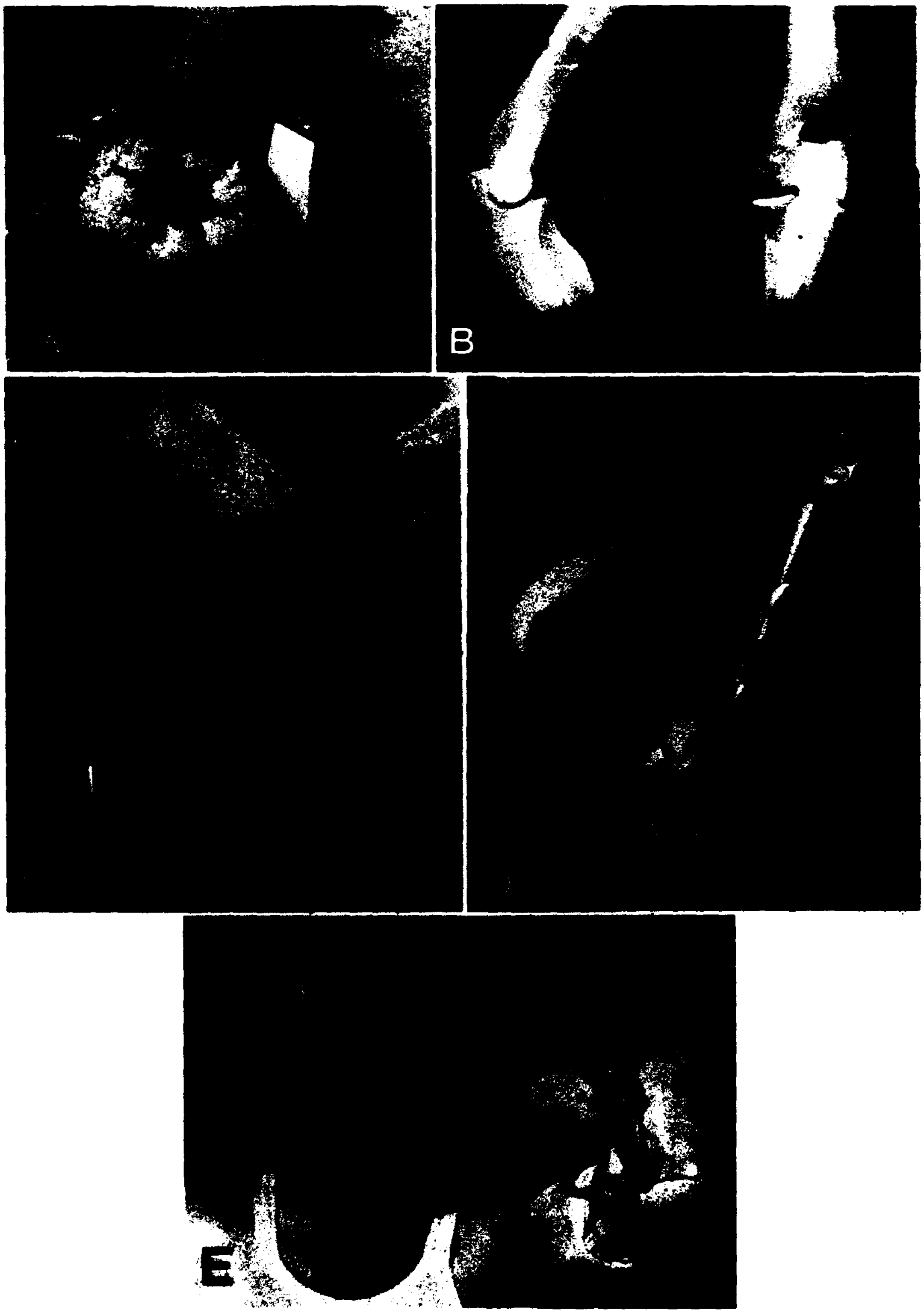

FIGURE 225.—*See opposite page for legend.*

The multiple-action elbow joint was considered indicated in all short forearm stumps that could not flex a prosthesis beyond 90 degrees. It was so designed that when the socket bar was flexed 90 degrees, the forearm traveled 135 degrees. This ratio was arrived at only after several different combinations had been tested. As already mentioned, however, it was necessary, to accept some loss of power as the price for the increase of 45 degrees in motion of the forearm. With persistence and patience, very good functional results were possible.

When the prosthesis was assembled, a figure-of-eight shoulder harness was attached to a Northrop control unit. It would have been ideal to have the multiple-action elbow joint custom-made for each individual, but this was obviously not practical.

Section IV. Amputations Through the Arm

TECHNIQUE

Amputation at the elbow joint.—Neither disarticulation at the elbow joint nor transcondylar amputations were originally looked upon with favor, for the sole reason that a suitable prosthesis had not been designed for use after them. Later, difficulties of fitting were largely overcome by the development, by the A. J. Hosmer Co., Los Angeles, Calif., of an efficient outside hinge that locked in any desired degree of flexion. Either transcondylar amputation or disarticulation at the elbow joint produced a flare at the end of the stump that had the advantage of a longer lever, while the bulbous end, if the prosthesis was properly fitted, prevented rotation of the socket (fig. 226).

Amputation at the lower and middle third of the shaft of the humerus.—Whenever amputation above the elbow was necessary, all possible length was preserved from the supracondylar region of the humerus proximally. The lower the amputation, the greater the strength of the stump and the better the control, since length produces better leverage.

The site of fractures of the humerus, with or without loss of bone, did not always determine the site of amputation. In one case, for instance (fig. 227), the shaft of the humerus was missing from the upper third distally, but redundant soft tissue was present, and it was possible, by the technique just described, to insert a segment of the fibula into the medullary canal of the remaining humerus. In a second case (fig. 228), the fibular graft was used as an intermedullary peg to fix the head of the humerus to the shaft in its anatomic position. In a third case (fig. 229), a compound comminuted fracture of the left humerus, with severance of the brachial artery, there was no response to treatment, and open circular amputation was performed at the lower third of the humerus. Ten months

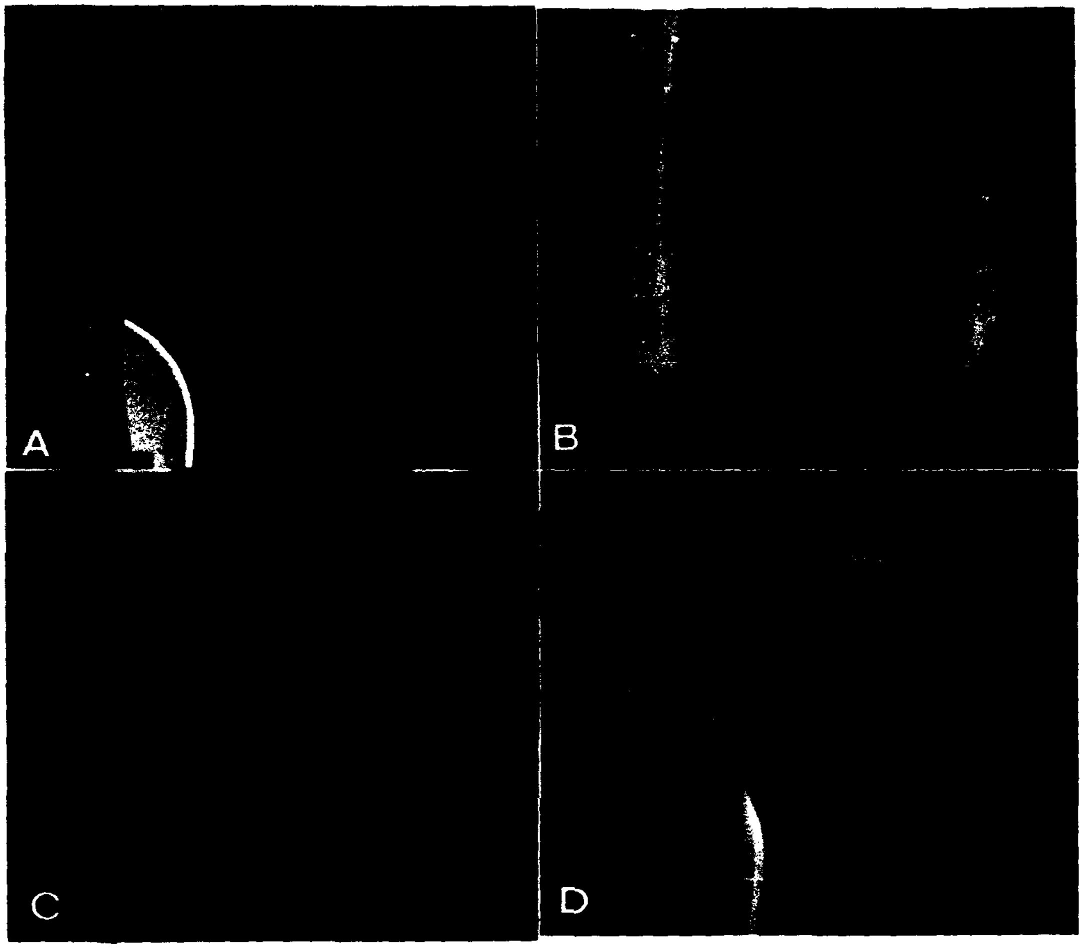

FIGURE 226.—Management of stump after transcondylar amputation. A. Appearance of stump 10 weeks after amputation. B. Anteroposterior and lateral roentgenograms before revision of stump. C. Same, after final revision. Note flare of condyles. D. End result.

later, cortical and osteoperiosteal grafts, secured from the tibia, were applied to the humerus and were well incorporated in it within 3 months.

Amputation at the upper third of the humerus.—Amputations at the junction of the middle and upper thirds of the humerus were attended with serious handicaps because of the regional anatomy; in this region, the low insertions of the pectoralis major, the latissimus dorsi, and the teres major prevent the socket from engaging the stump. In such cases (fig. 230), the pectoralis major was freed from its insertion, reflected under the coracopectoralis fascia, and attached by a mattress suture to the fascia near the coracoid process. The insertions of the latissimus dorsi and teres major were transferred higher on the shaft to be attached to the fascia near the bicipital groove. In this manner, when the obstruction caused by the insertions of these muscles was removed, the cylinder of the

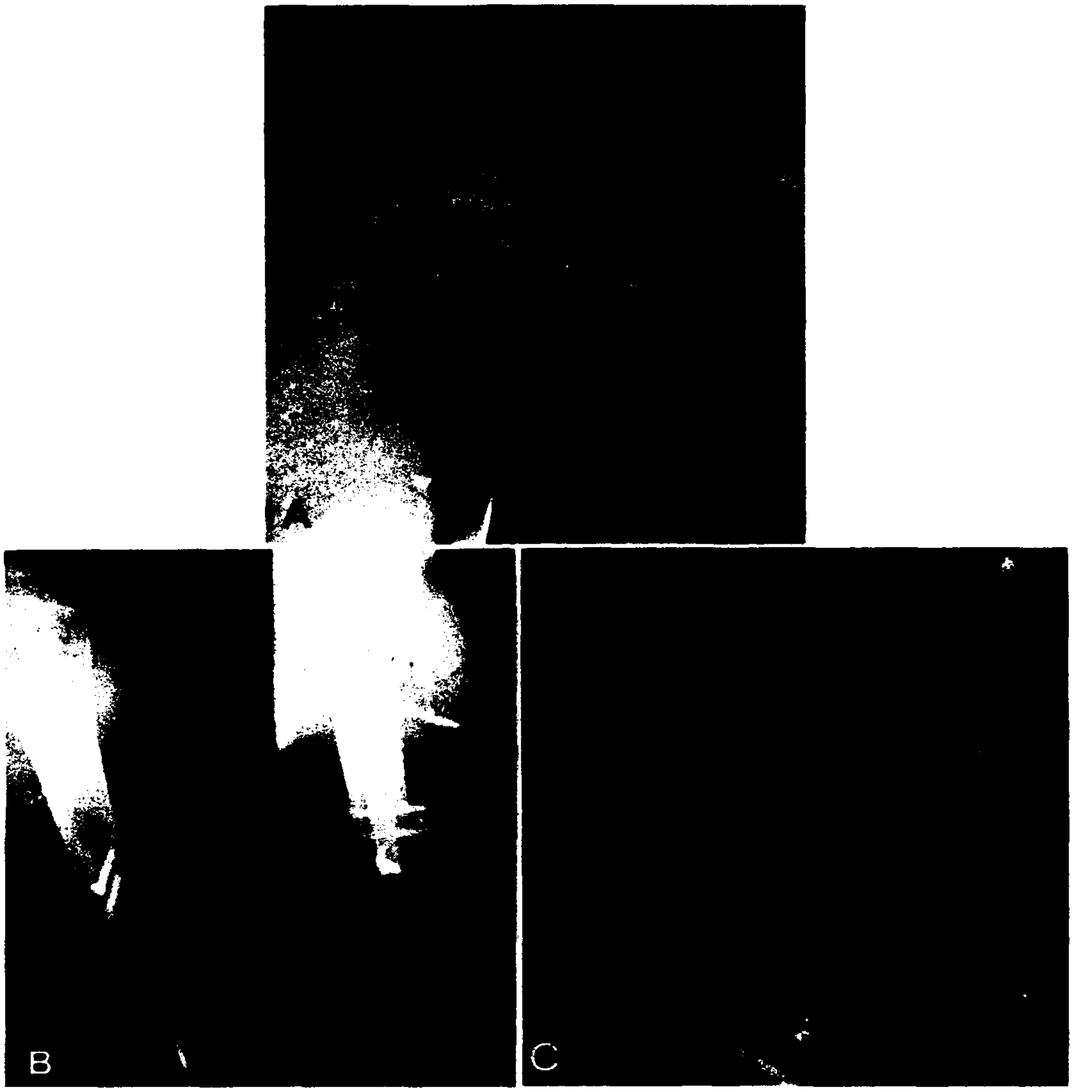

FIGURE 227.—Management of left above-elbow stump with redundant soft tissue. A. Redundant soft tissue remaining after removal of shaft of distal humerus. B. Anteroposterior and lateral roentgenograms, showing lengthening of humerus by fibular bone graft. Note multiple drill holes in distal portion of graft. C. Appearance of stump after lengthening of humerus by fibular graft.

prosthesis could extend farther into the axillary region and better encase the stump.

When only the head of the humerus remained in situ (fig. 231), it was left in place, to fill the glenoid fossa and to aid in rounding out the shoulder and keeping its natural symmetry. It had no function beyond adding to the wearer's comfort and filling the sleeve.

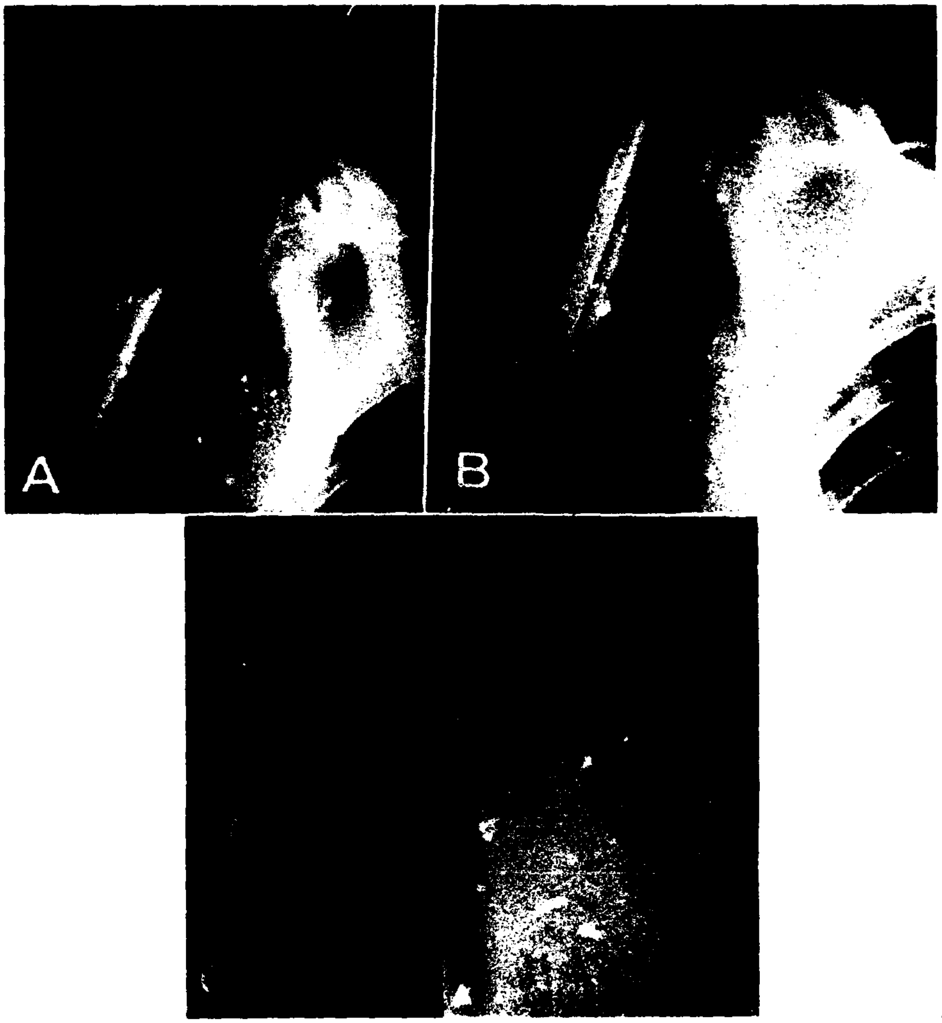

FIGURE 228.—Management of right above-elbow stump with un-united fracture of surgical neck of humerus. A. Anteroposterior roentgenogram showing un-united fracture with abduction of head of humerus. B. Same, after correction of deformity and nonunion by intermedullary fibular graft. C. Appearance of stump after revision.

PROSTHESES

For satisfactory fitting of a prosthesis in amputations above the elbow, a minimum length of 2 inches below the insertion of the pectoralis major was necessary (fig. 230D). The stump was, therefore, always left as long as possible, since both the control and the usefulness of this prosthesis were dependent upon the factor of length.

Plastic sockets were preferred because of their light weight and the ease with which they could be kept clean, but plastic materials were not

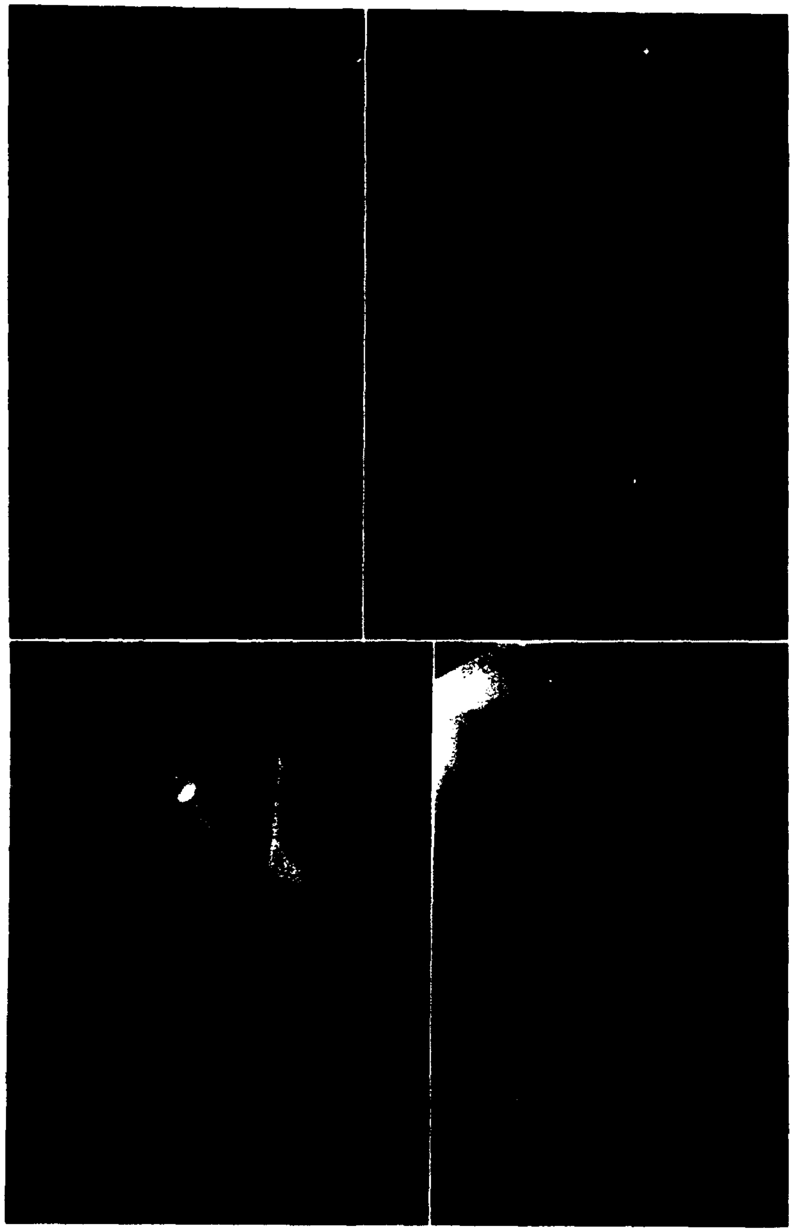

FIGURE 229.—Management of left above-elbow stump with compound comminuted fracture of humerus. (Top) Anteroposterior and lateral roentgenograms, showing involucrum bridging defect in humerus, with pseudoarthrosis. (Bottom) Same, showing graft of humerus with bone from tibia and osteoperiosteal onlay.

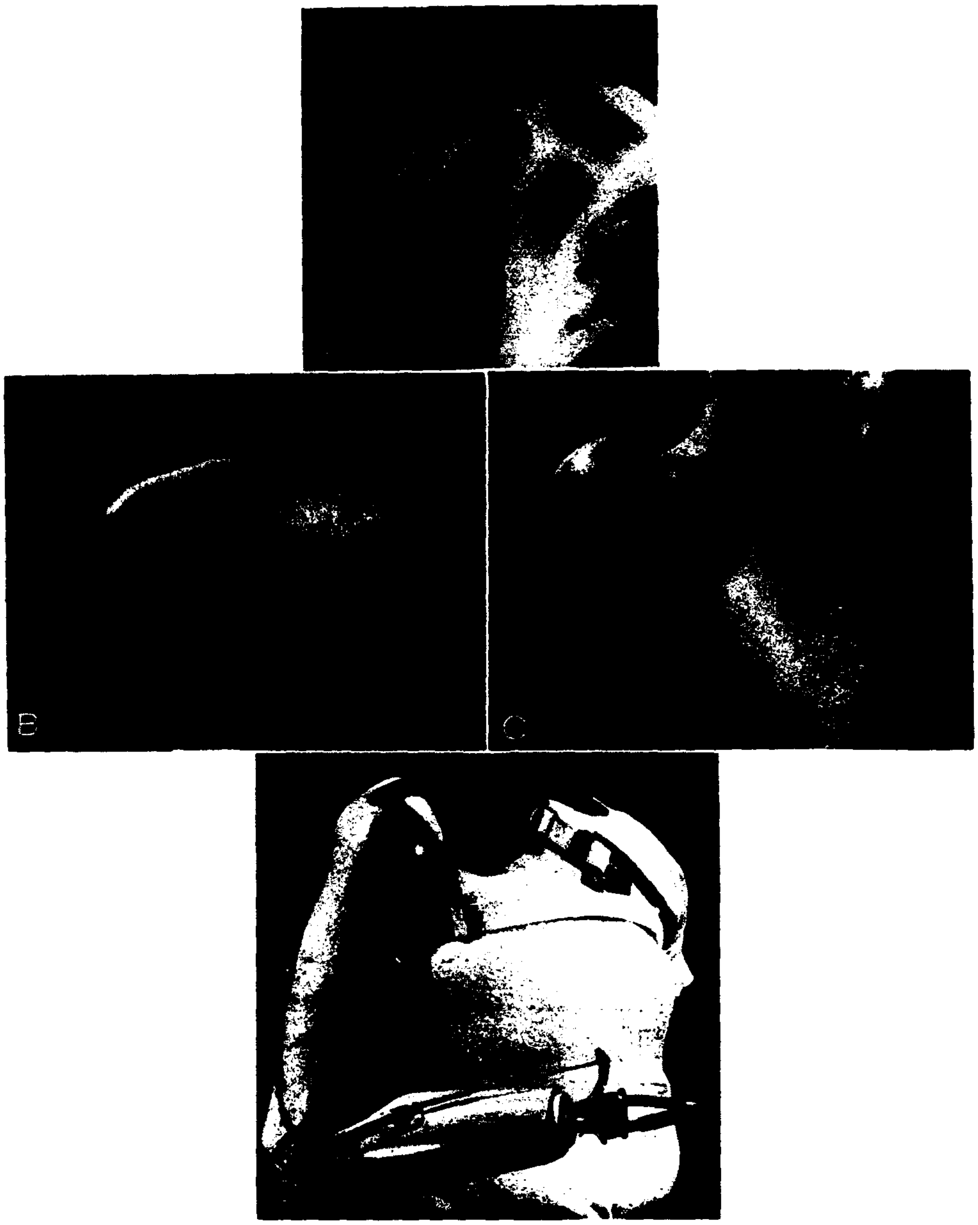

FIGURE 230.—Management of right above-elbow stump. A. Anteroposterior roentgenogram, showing length of humerus after amputation at level of pectoralis major insertion. B. Appearance of stump after transfer of insertions of pectoralis major, latissimus dorsi, and teres major, to decrease their obstructing effect on anterior and posterior axillary folds. C. Same, lateral view. D. Prosthesis in place.

introduced until late in the war and were never available in sufficient quantity for general use. Therefore, the sockets, which were usually rigid, were commonly made of wood, fiber, metal, or leather.

The hinged joint which provided the elbow mechanism was incorpo-

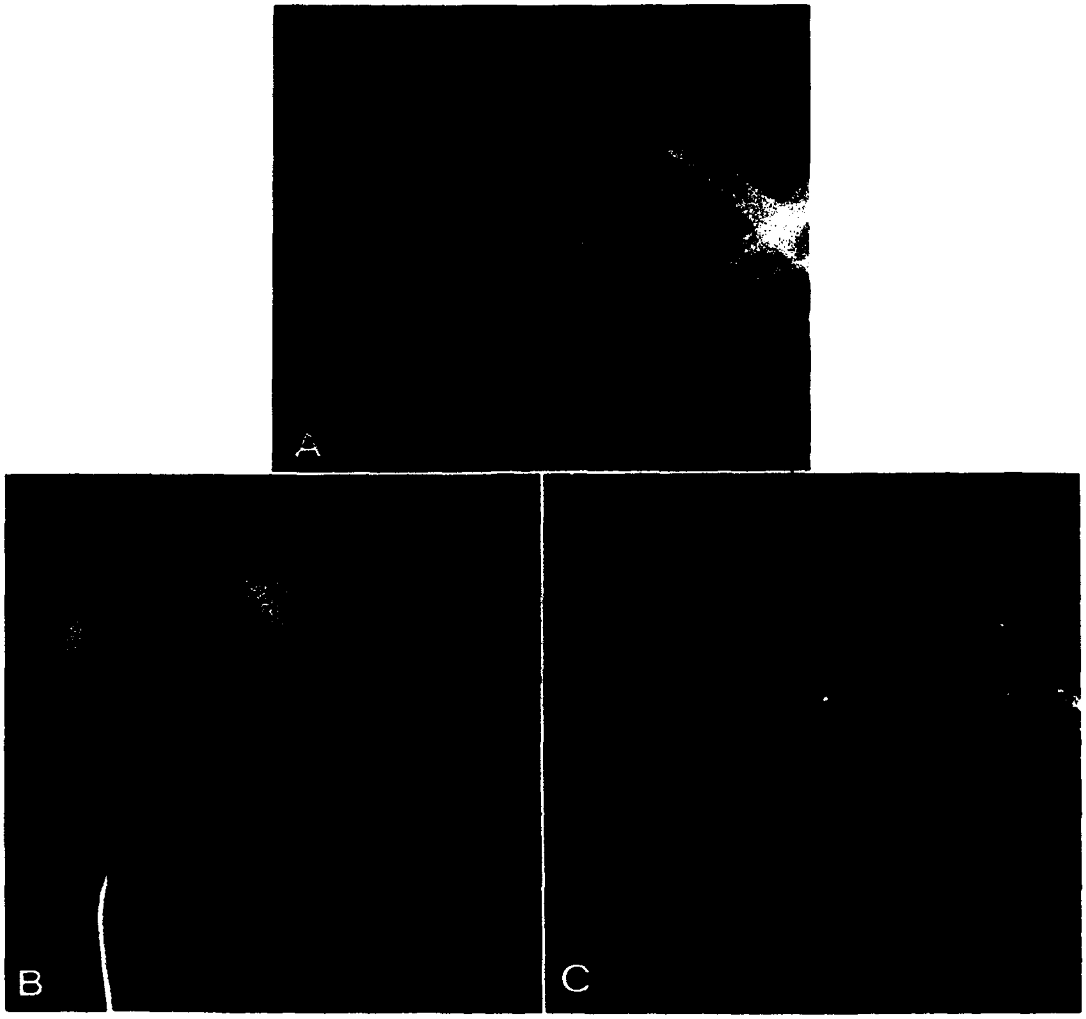

FIGURE 231.—Management of right above-elbow stump with head of humerus in glenoid fossa. A. Anteroposterior roentgenogram, showing head of humerus in glenoid fossa. B. Appearance of shoulder. Note rounded contour. C. Lateral view.

rated in the lower portion of the socket. It was attached to a forearm section, which was made of the same material as the socket and which included the hand or hook usually used in below-elbow prostheses.

The usefulness of a prosthesis of this kind was definitely limited.

Section V. Amputations at the Shoulder

TECHNIQUE

Humeroscapular (shoulder) disarticulation.—Loss of the arm at the shoulder was associated with two serious problems, one cosmetic and the

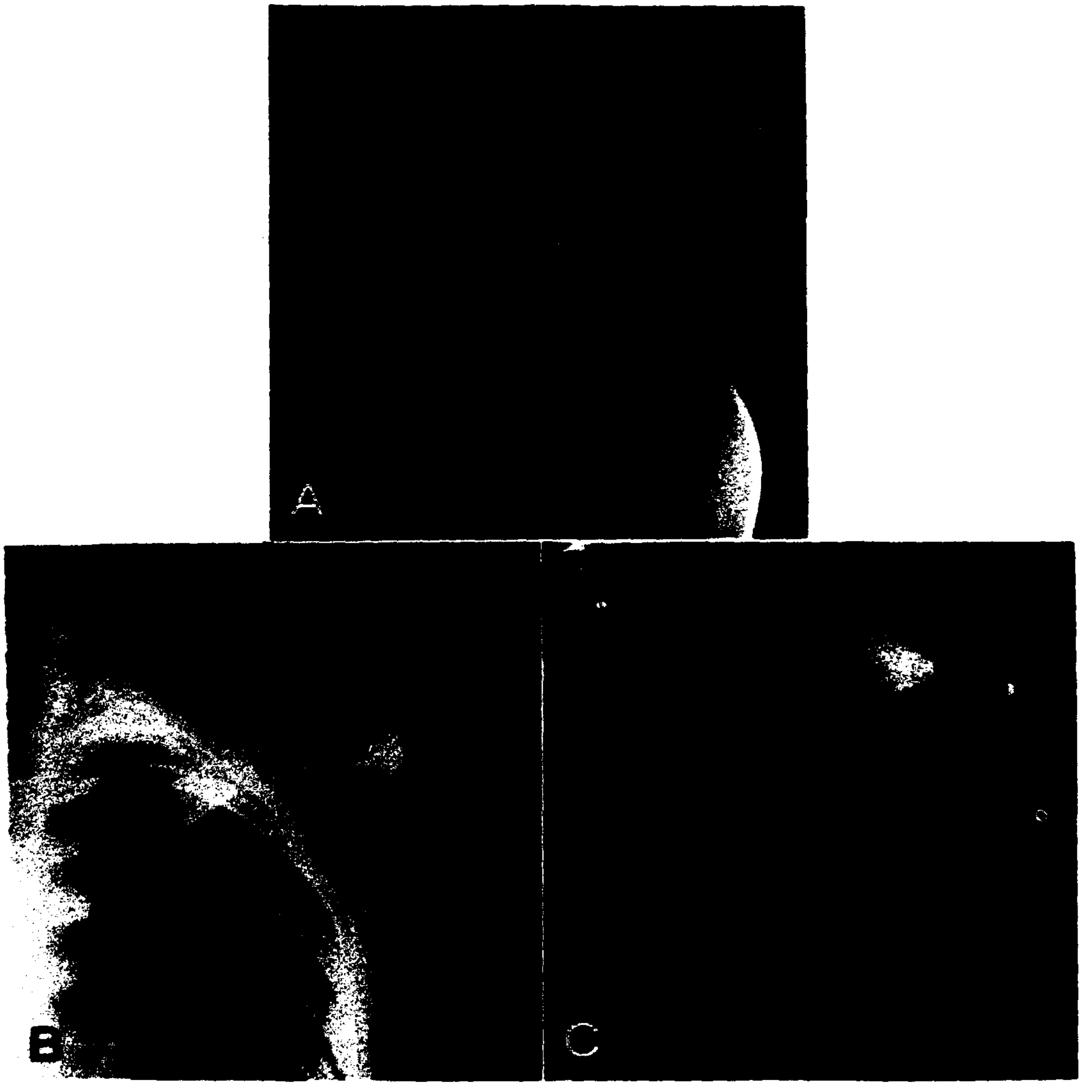

FIGURE 232.—Management of left shoulder after humeroscapular disarticulation. A. Appearance of shoulder before revision. Note elevation and acromial prominence, which made pressure of clothing painful. B. Anteroposterior roentgenogram, showing correction of bony prominence by creation of fracture of acromion. C. Appearance of shoulder after revision.

other physical. An associated atrophy of the musculature of the shoulder girdle always occurred, and the affected shoulder was always elevated because of loss of the counterbalancing effect of the arm. The normal bony prominences, especially in slender individuals, therefore, became accentuated as well as tender because of the friction of clothing over them. Abnormal prominences caused by acromioclavicular separations and malunited fractures were even more bothersome. A tender spot on the shoulder interfered with the normal swing of the prosthesis in walking, and patients were disinclined to wear it.

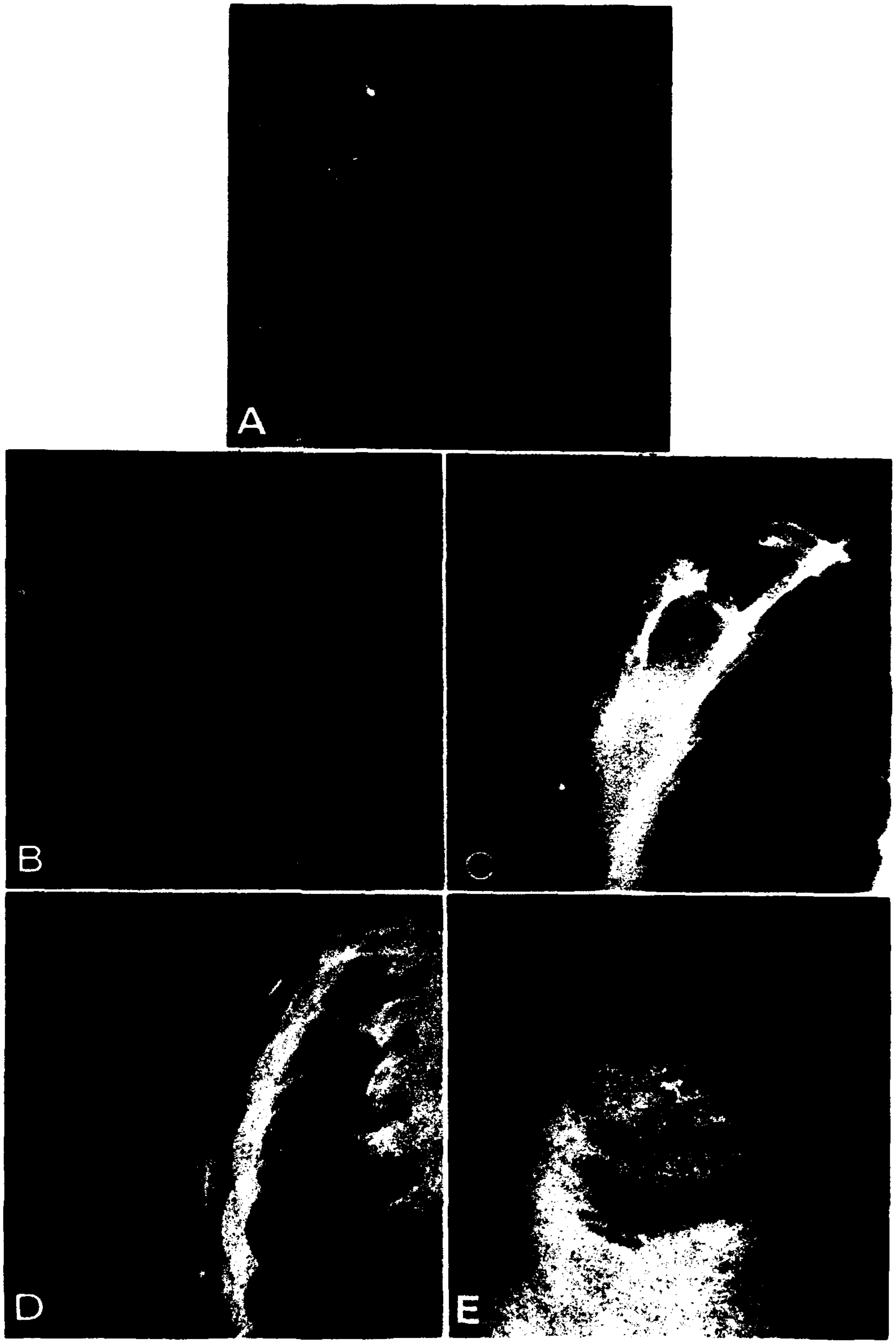

FIGURE 233.—*See opposite page for legend.*

Surgical correction of these deformities (fig. 232) added to the patient's comfort and was of cosmetic value in the restoration of approximately normal shoulder symmetry. A fracture was created in the prominent acromion by cutting the anterior cortex just lateral to the acromioclavicular joint and bending the acromion downward. When the clavicle was elevated because of an acromioclavicular separation, the distal inch of the clavicle was removed. Painful exostoses from malunited fractures were also excised. Easy approaches were found through short anterior incisions or through the scars of the old injury.

When the glenoid, acromion, body of the scapula, and outer clavicle were disorganized, the protuberances were removed, the nerves were carefully dissected free from scar tissue, and plastic closure of the skin was done (fig. 233). The objective of the operation was to preserve as much as possible of the shoulder girdle and its musculature.

Interscapular thoracic (forequarter) amputation.—Forequarter amputation involved the removal of an entire upper extremity with the scapula and clavicle, leaving in situ only the chest wall and its skin covering. A complete artificial limb could not be attached satisfactorily after such surgery, and attempts to fit a prosthesis were, therefore, not indicated. A light shoulder pad, its contour matching that of the opposite shoulder, was used to conceal part of the deformity and improve the general appearance. It was made of leather and canvas, filled with sufficient padding to maintain its shape, and held in place by a strap that extended around the axilla on the opposite side of the body. A still more satisfactory prosthesis was a hollow, molded plastic shoulder, which was much lighter than the leather and canvas appliance and which permitted more satisfactory ventilation.

PROSTHESES

Considerable dexterity occasionally was achieved with a prosthesis after disarticulation at the shoulder, but most patients preferred not to wear one. Similarly, most patients who had undergone any type of forequarter amputation preferred not to use an artificial appliance; there was no stump to activate it, and it was simply of cosmetic value. Some amputees, however, wore them for this reason. Devices for this purpose were made as simple and as light as possible. They consisted of three components, (1) a socket of molded leather or plastic extending to the elbow,

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FIGURE 233.—Management of osteomyelitis with sequestration after disarticulation of right shoulder. A. Lateral view of shoulder 10 weeks after initial amputation. Note sequestra in open wound. B. Anterior view at same time. C. Anteroposterior roentgenogram at same time, showing remaining portion of scapula and clavicle. D. Same, after sequestrectomy and debridement. E. Lateral view of shoulder after final plastic closure.

(2) a forearm segment, and (3) a hand. The socket was fitted to the chest wall and held in place by a strap across the chest or by a cloth waistcoat sewed to the socket. This prosthesis was improved by the use of lightweight materials.

References

1. Medical Department, United States Army. Surgery in World War II. Hand Surgery. Washington: U.S. Government Printing Office, 1955.

CHAPTER XXXIII

Amputations of the Lower Extremity

Leonard T. Peterson, M.D.

Section I. Amputations of the Foot

The total number of partial amputations of the foot performed during World War II (p. 870) was not large, absolutely or proportionately, but the creation of satisfactory stumps and the fitting of satisfactory prostheses gave rise to numerous problems.[1]

The Syme technique was most frequently employed (amputation just above the articular surface of the ankle, fig. 234). The Chopart technique (amputation at the mid tarsal level) and the Lisfranc's technique (amputation at or near the tarsometatarsal joint) were employed much less frequently.

When patients who had undergone partial amputations of the foot were received in the Zone of Interior, usually the stump was still open, the healing process was progressing but was not yet complete, and the remnant of the foot was in some degree of equinus or varus or both.

PARTIAL AMPUTATION OF THE FOOT THROUGH THE TRANSVERSE AXIS

Chopart amputation.—The Chopart technique was seldom the procedure of choice in Army hospitals either in the Zone of Interior or in combat zones except as an emergency procedure. U.S. prisoners of war had sometimes been subjected to it by surgeons of other countries. When these casualties were received in amputation centers in the Zone of Interior, usually after a long interval, they had often been walking on the stumps for some time, with the aid of boots stuffed with paper or other materials. Theoretically, it was always desirable to convert a Chopart stump into a Syme stump, but it was not always the best policy. If the Chopart stump was healed and in good condition, many surgeons, doubting that they could improve conditions present, were hesitant to advise further surgery,

[1] Much of the material in this chapter is derived from reports specially prepared for the history of orthopedic surgery in World War II by Dr. (formerly Maj., MC) Rufus H. Alldredge, Dr. (formerly Capt., MC) Charles Highsmith, Jr., Dr. (formerly Lt. Col., MC) Edward C. Holscher, and Dr. (formerly Maj., MC) Harry D. Morris.

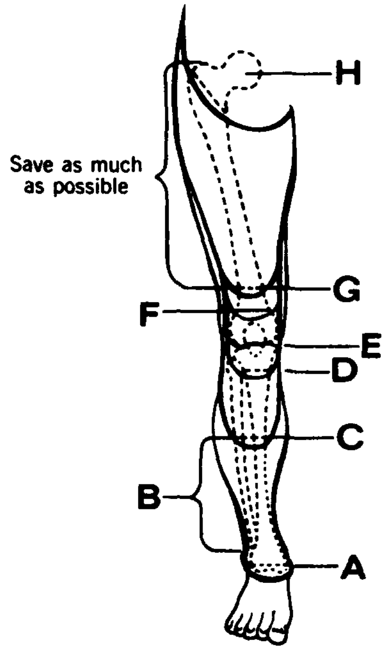

FIGURE 234.—Sites of major amputations in lower extremity. A. Syme amputation. B. Possible levels of amputation in lower portion of leg. Prostheses can be fitted at these levels, but the stumps are generally undesirable and the fittings are often unsatisfactory. C. Ideal below-knee stump, 5 to 7 inches below joint, with fibula 1 inch shorter than tibia. D. Short below-knee stump, which can be fitted when it is as short as 1½ inches if leg is not too fleshy. A below-knee stump too short to be fitted with a socket may be fitted in flexion with a knee-bearing prosthesis. E. Disarticulation at knee. F. Level of supracondylar tendoplastic and Gritti-Stokes amputations. G. Amputation above knee, at least 3 inches or more above center of knee joint. H. Disarticulation at hip or amputation near hip.

and patients were equally reluctant to undergo it. If, however, the stump was still open and it was difficult or impossible to close it at this level because of insufficient skin and soft tissue (fig. 235), a Syme amputation was performed.

Prostheses could be fitted to Chopart stumps in three ways:

1. The amputated portion of the foot was replaced by a leather container made from a plaster mold of the stump and stuffed with sponge rubber or felt (fig. 236). This device was worn in a laced boot made with a steel shank in the sole and reinforced with straps that originated on either side of the heel and buckled around the ankle.

2. A panastragalar arthrodesis was performed, usually in two stages (fig. 237), and the stump was fitted with the boot just described.

3. A prosthesis of the standard type (fig. 238) was used, sometimes after panastragalar arthrodesis but more often without surgery. The leg portion of the prosthesis was made of leather, wood, metal, or plastic. The foot was of wood or of a combination of felt and wood. The sole, of rubber, was provided with the usual toe break. There was no ankle joint. The stump and leg were inserted posteriorly into the prosthesis, which was held in position by a laced leather corset.

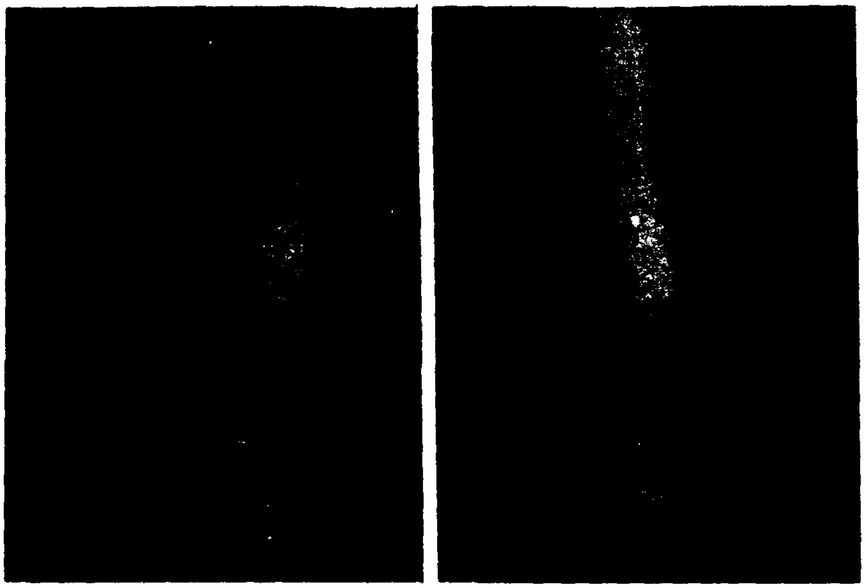

FIGURE 235.—Healed stump of right foot after open amputation through tarsometatarsal region. There was insufficient skin and soft tissue to close the wound. A Syme amputation was therefore performed, with very satisfactory results. (Left) Anterior view. (Right) Medial view.

Lisfranc's amputation.—Both functionally and esthetically, the Lisfranc's amputation was superior to the Chopart operation. The stump could be fitted more easily, and the construction of the prosthesis was simple. It consisted of a boot containing a leather socket made from a mold of the stump. The toe of the boot was filled with sponge rubber or felt and a steel shank was incorporated in the sole. Reinforcing straps were used as necessary.

If a low-quarter shoe was desired after a Lisfranc's amputation, an ankle support had to be used to keep it on (fig. 239). A plaster mold of the stump was fitted with a leather insole, sometimes built up with sponge rubber to fit the longitudinal arch, and the missing toes were replaced by sponge rubber covered with soft leather. A laced leather ankle support attached to the leather insole held the shoe on the foot. A steel shank was incorporated in the sole of the shoe. A prosthesis of this kind functioned quite satisfactorily, but the boot type was more substantial and presented a better appearance.

The Lisfranc's technique was not used very often because there were not many opportunities to save as much soft tissue as it required.

Amputation through the metatarsal shafts.—Amputation through the metatarsal shafts was the commonest of all partial amputations of the foot. It was sometimes performed for gangrene resulting from exposure to low temperatures. In fact, the only stumps that could be fitted after pri-

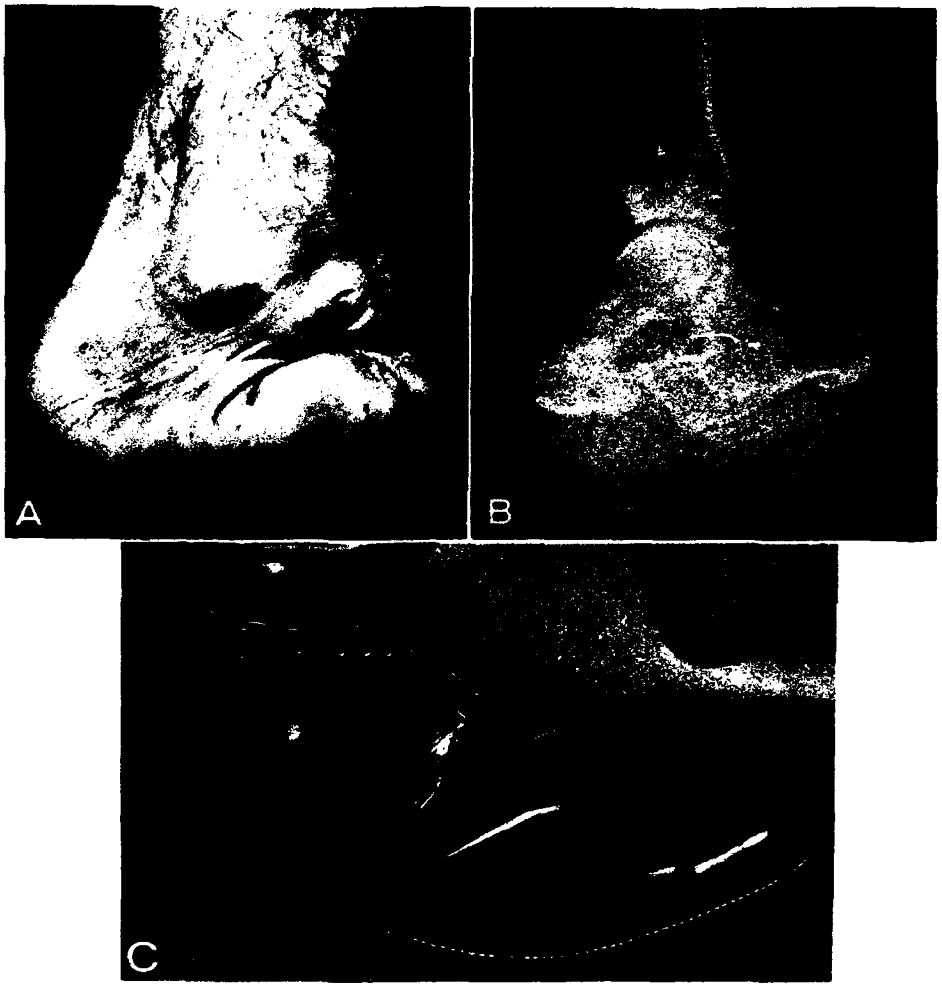

FIGURE 236.—Stump left after Chopart amputation, with satisfactory tissue covering weight-bearing surface. A. Anterolateral view of stump. B. Lateral roentgenogram of stump. C. Prosthesis consisting of laced boot with reinforcing leather straps and stuffing to compensate for defect.

mary amputation without revision or reamputation were the small group in which dry gangrene had developed after frostbite and trenchfoot. In these cases, there was no infection, normal tissue was present below the knee, and primary closed amputation could be performed with perfect safety.

Several techniques were employed for amputation through the metatarsal shafts (figs. 240 and 241):

1. Amputation straight across the long axis of the foot.
2. Amputation obliquely across the shafts of the metatarsals in one direction or the other.
3. Partial or complete amputation of the second, third, and fourth metatarsals, with the first and fifth left intact.

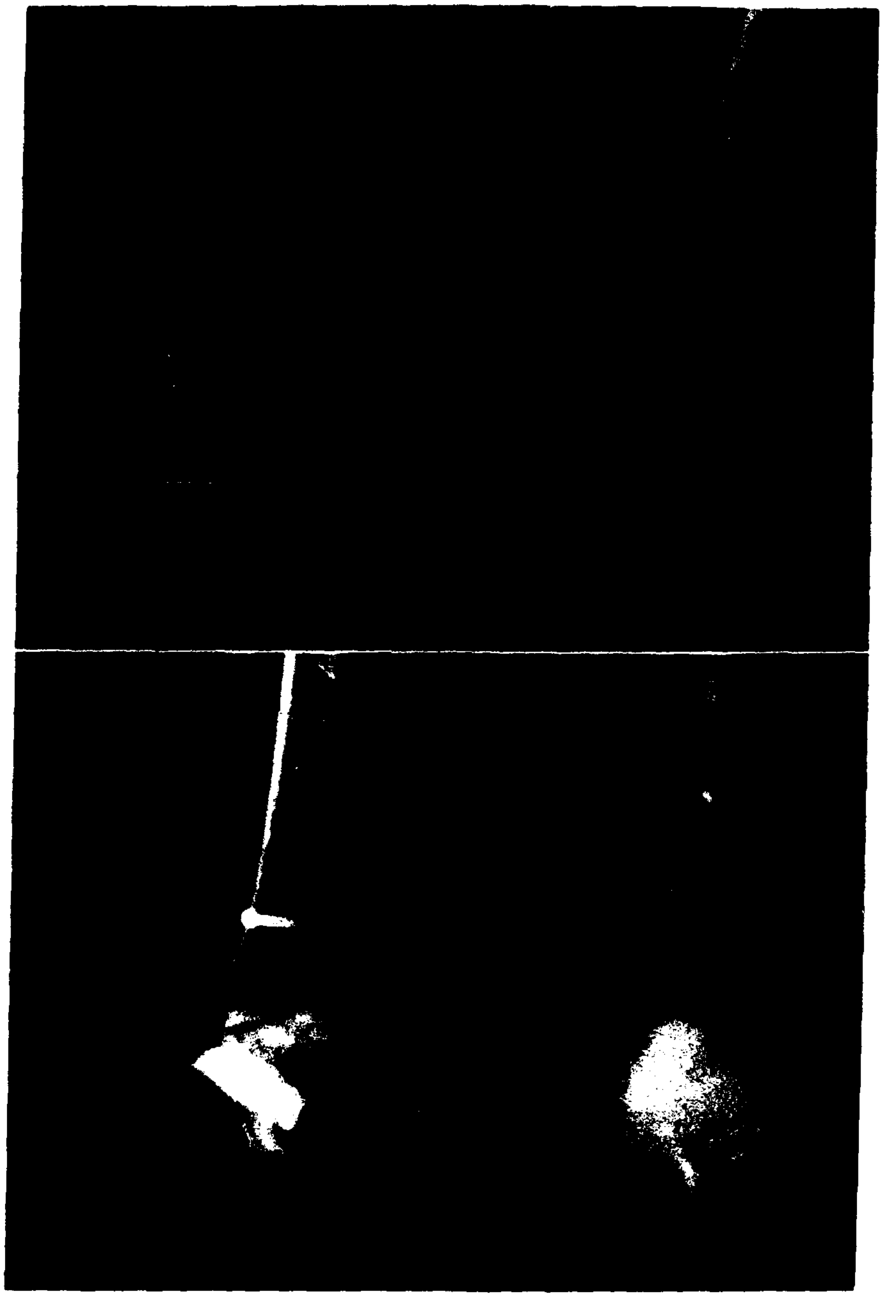

FIGURE 237.—Stump of left foot after Chopart amputation. (Top) Anteroposterior and lateral roentgenograms of stump before revision. (Bottom) Lateral and anteroposterior roentgenograms after panastragalar arthrodesis. Note use of screw in arthrodesis of distal fibula to tibia.

4. Partial amputation through the metatarsal region of one foot combined with amputation of the opposite leg, often as the result of landmines (fig. 242).

Revision of the stumps was carried out according to the indications

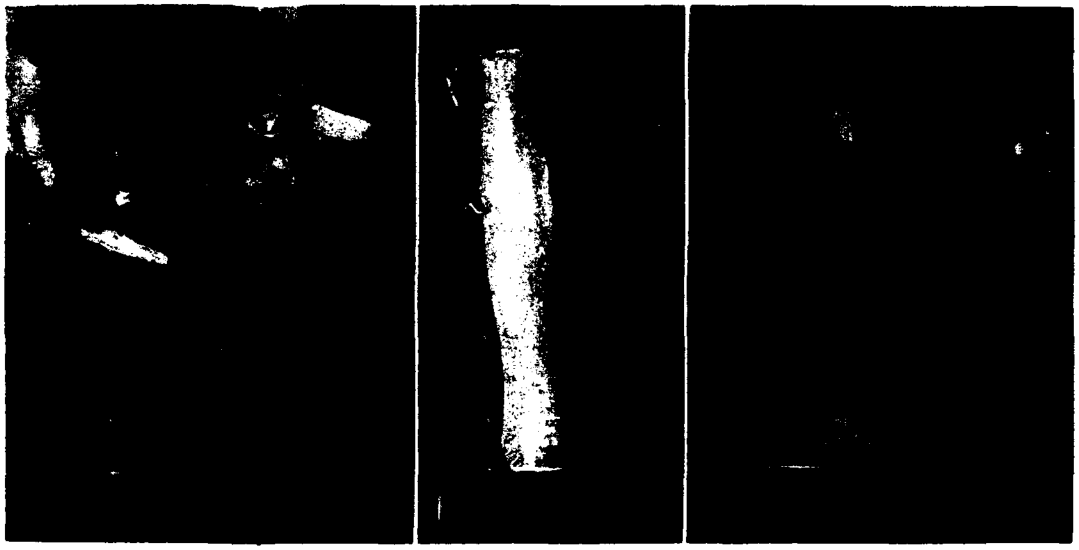

FIGURE 238.—Prosthesis for use after Chopart amputation of foot. A. Lateral view, with posterior shell removed. B. Posterior view with shell removed. C. Posterior view with shell in place.

FIGURE 239.—Adaptation of low-quarter shoe to stump left after Lisfranc's amputation. (Left) Stump (anterior view), prosthesis, and shoe. (Right) Lateral roentgenogram of stump.

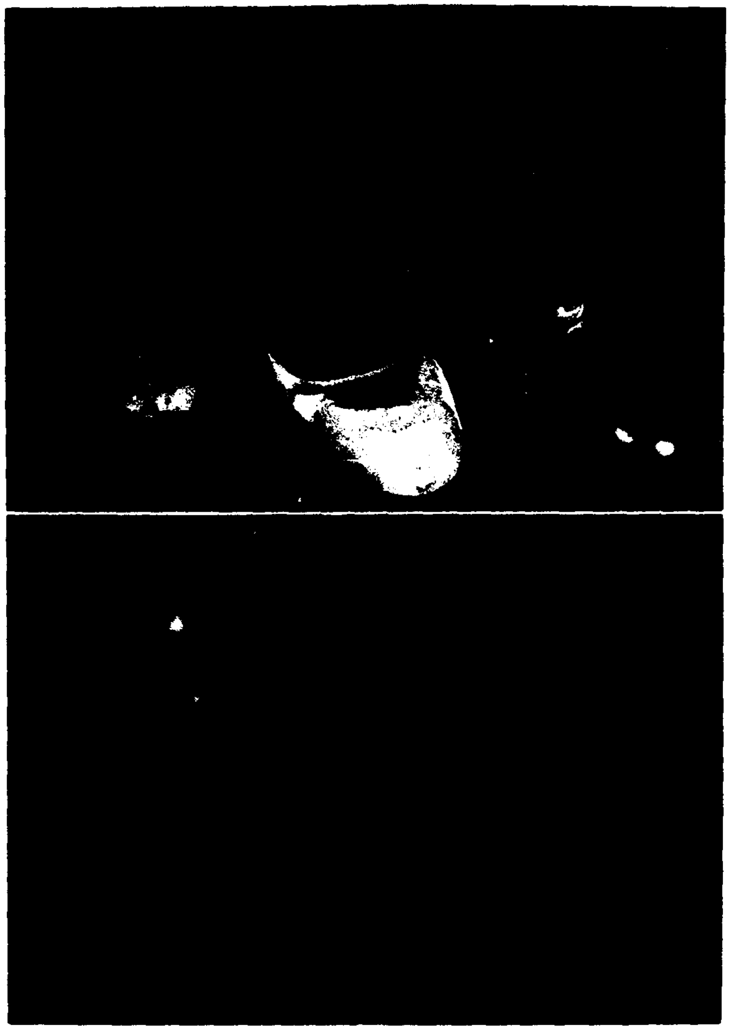

FIGURE 240.—Healed stump after amputation through forefoot. (Top) Anterior view of stump, leather arch support and sponge rubber filler, and low-quarter shoe (metatarsal bar on sole is not shown). (Bottom) Anteroposterior and oblique roentgenograms of stump.

of the individual case. Great care was taken to preserve as much length as possible and to leave as little scar tissue as possible over the stump end.

Stumps of this kind could be fitted so well with the low-quarter prosthesis just described that the patients could walk painlessly and without an ankle support to hold the shoe on the foot.

Disarticulation of the toes.—Amputation of all toes on one or both feet was encountered only occasionally. A prosthesis for such injuries consisted of a combination longitudinal and metatarsal arch support, with a steel shank in the sole of the shoe. In some instances in which the loss of the toes had been caused by freezing, function was complicated by complete anesthesia of the sole and the subsequent trophic disturbances.

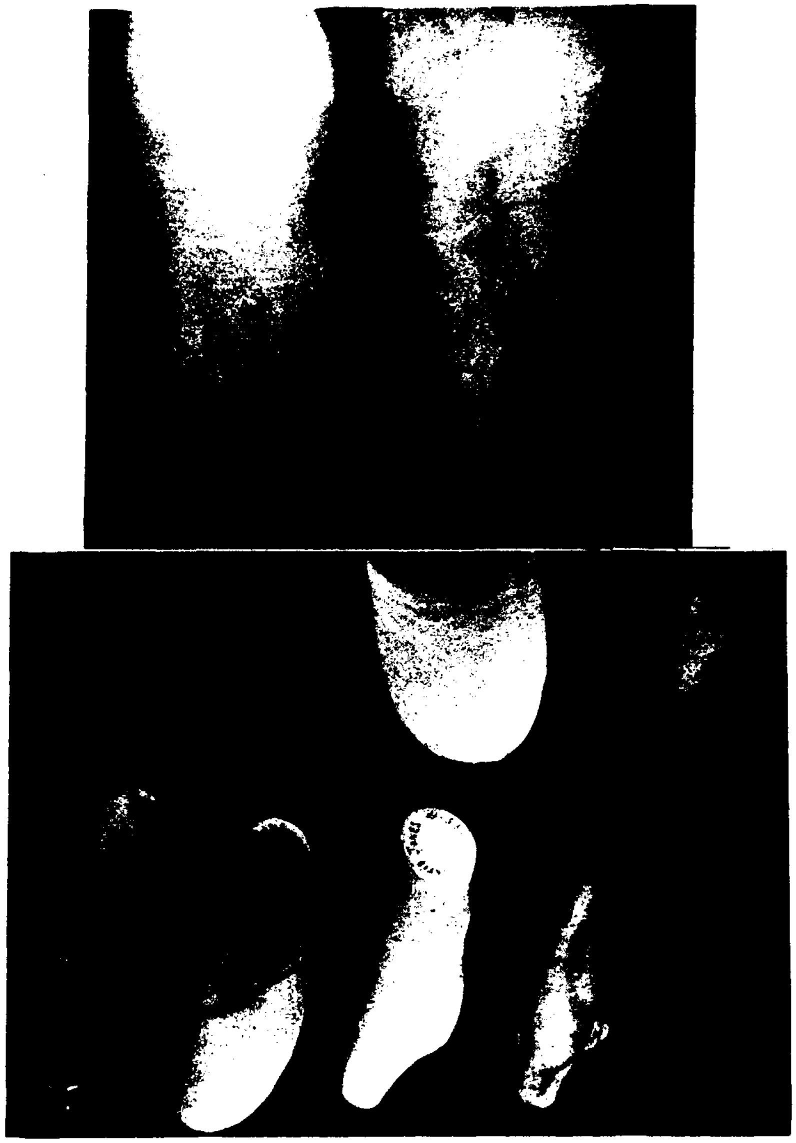

FIGURE 241.—Partial amputation of left foot of casualty who had also sustained amputation of the right leg. (Top) Anteroposterior view of stump and of plaster model from which prosthesis (also shown) was constructed. Shoe fitted with steel shank and metatarsal bar (not shown). (Bottom) Anteroposterior and lateral roentgenograms of stump.

PARTIAL AMPUTATION OF THE FOOT THROUGH THE LONGITUDINAL AXIS

Partial loss of the foot in the longitudinal axis ranged from the loss of one or two toes and the corresponding metatarsals to the loss of as many as four toes and the corresponding metatarsals.

FIGURE 242.—Casualties who underwent partial amputation of foot through metatarsal region and amputation of contralateral extremity. In each instance, the foot could be fitted with a prosthesis without additional surgery.

A casualty who had lost only one or two toes and the corresponding metatarsals was fitted with a leather arch support attached to a sponge rubber filler. A metatarsal bar was attached to the sole of the shoe, but a steel shank was not usually required. The same type of prosthesis could be used when the loss (fig. 243) consisted of the lateral three or four toes; the medial two or three toes; and all four of the lateral toes, with the retention of the great toe and the corresponding metatarsal. A prosthesis for these injuries consisted of a sponge rubber filler covered with leather, constructed from a plaster mold of the foot and attached to a leather insole. Men who had lost two or three toes with their metatarsals did not have as good function as those who had lost the corresponding lateral structures.

THE SYME AMPUTATION

Advantages.—At the onset of World War II, few surgeons in the United States were familiar with the Syme amputation, the only definitive amputation performed near the ankle joint. As its advantages became evident and experience with it increased, it came into more general use. Almost 2 percent of all Army amputees were operated on by this technique, and the number would probably have been larger if more surgeons had been familiar with it earlier and had used it as an alternative to mid-foot or below-knee amputations.

FIGURE 243.—Stump left after amputation of lateral aspect of foot in longitudinal axis, with removal of third, fourth, and fifth toes and corresponding metatarsals. (Top) Anterior view of stump. Thin leather insole with sponge rubber filler to compensate for defect. Shoe. (Bottom) Lateral view of foot with prosthesis in position. Function in amputation handled in this manner was usually excellent.

The Syme amputation had definite advantages over both techniques just described: It was more conservative. It gave better functional results than a below-knee amputation. The longer stump provided good leverage and was capable of full end-bearing whether or not a prosthesis was used. It was entirely possible for a Syme amputee to walk about the house without a prosthesis (fig. 244). On the whole, the Syme stump was simpler

FIGURE 244.—Stumps after bilateral Syme amputations. (Left) Anterior view, showing bare stumps on which patient could stand and move about without support. (Right) Same, with temporary prostheses in place.

to fit than a below-knee stump, and the prosthesis did not require as many adjustments. Since it did not extend above the knee, a pelvic belt for suspension of the artificial limb was not required. Gait was better than with the Chopart amputation, and casualties had far fewer complaints of pain and discomfort.

With bilateral loss of the lower limbs, bilateral Syme operations were preferable to bilateral below-knee amputations. The gait was more normal, and standing was possible for longer periods. When, for any reason, bilateral Syme amputations were not possible, it was always desirable to use the Syme technique on one side, with amputation above or below the knee on the other side (fig. 245), so that the patient could depend upon the Syme stump for better locomotion and prolonged standing.

Results with the Syme amputation improved as experience with it increased. The bulbous ankle which resulted (and which made it an unsatisfactory technique for women, for obvious cosmetic reasons) was criticized by some limb-fitters, but patients did not object to it. Most of them, in fact, genuinely liked the Syme stump.

In an interesting discussion at the symposium on amputations of the American Orthopaedic Association in June 1944, Col. R. I. Harris, RCAMC, expressed the Canadian satisfaction with this technique (*1*). It was the most useful of all lower limb amputations, he said, because of the "perfection of its weight-bearing qualities." It might be somewhat more com-

FIGURE 245.—Casualties who underwent amputation below knee on one side and Syme amputation on the other. Without exception, all preferred the Syme stump to the opposite below-knee stump.

plicated than a below-knee amputation, but it was within the competence of any good surgeon. Colonel Harris admitted that British surgeons at the amputation center at Roehampton would not agree with him without some qualifications. At this time, they considered that the Syme stump had no better weight-bearing properties than any other below-knee stump, and they reported ulceration and circulatory disturbances after it. These complications were entirely contrary to the Canadian experience and United States surgeons also observed them in very few instances.

Indications and contraindications.—The Syme amputation had a rather limited field, and careful selection of cases was necessary for good results.

This operation was never indicated as a procedure for trauma under military circumstances, and it was never undertaken as a revision operation until the original wound was completely healed (fig. 246). Its use in the presence of infection and surgical trauma was an invitation to failure.

The operation was clearly indicated in young men in good physical condition who had suffered the traumatic loss of the greater part of the forefoot. It was also indicated when the loss of the foot was caused by exposure to freezing temperatures provided that persistent tenderness was not present in the soft-tissue covering of the heel, which would have to serve as the end-bearing surface of the stump. Most important of all criteria, the Syme operation was indicated only when there was adequate skin over the heel and sole, with good nerve and blood supply, for weight-bearing coverage of the end of the stump (fig. 247). An inch of good plantar skin on the heel fulfilled this requirement.

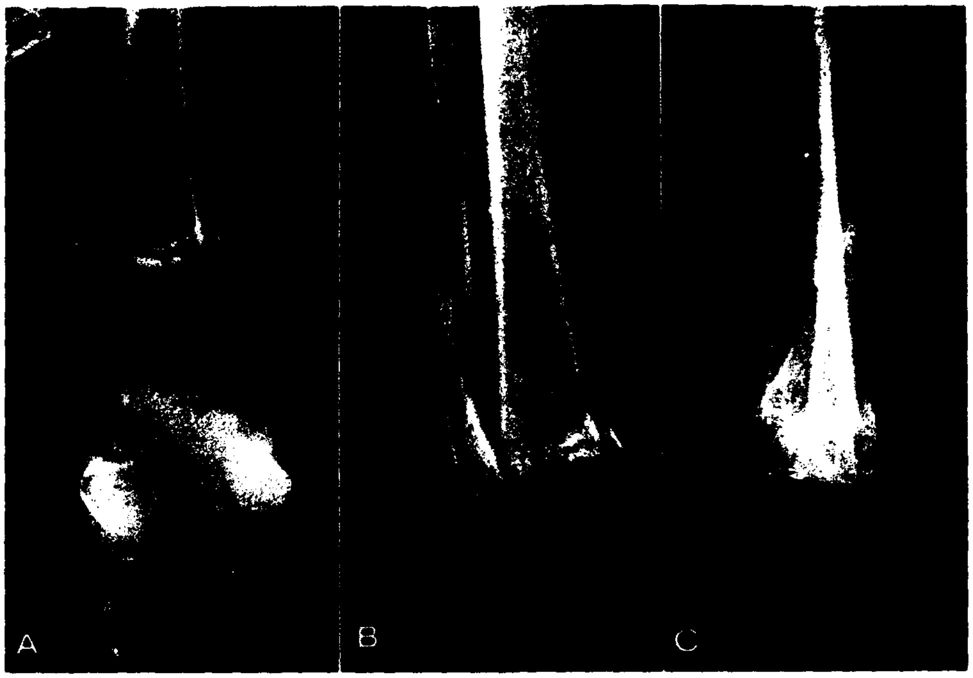

FIGURE 246.—Combined partial amputation of right foot with fracture of distal tibia and lower third of fibula. A. Anteroposterior roentgenogram of foot and ankle showing fractures, which were allowed to unite in this position before Syme amputation was performed. B. Same, after Syme amputation. C. Same, lateral view. Although the saw line in this instance was not perpendicular to the long axis of the leg, a perfect Syme stump was obtained.

Technique.—A Syme amputation (fig. 248) consisted of transection of the tibia and fibula just above the level of the ankle joint, removal of the lower fragments of these bones and of the tarsus and metatarsus in toto, and coverage of the ends of the tibia and fibula with the flap of heel left in situ.

Operation was performed with the extremity resting on a wood block about 10 inches high. A pneumatic tourniquet was used routinely.

The greatest care was taken not to damage the posterior tibial vessels during the dissection of tendons and nerves. Complete hemostasis was also highly important. After the tourniquet had been removed, all bleeding vessels were clamped and ligated with fine ligatures until as dry a field as possible had been secured.

Management of the heel flap was another very important point of technique. The flap was centered over the end of the stump and held in place there while it was sutured to the skin of the anterior surface of the leg with interrupted sutures. No subcutaneous sutures were used. The suture line thus formed ran straight across the anterior aspect of the stump. Early in the war, it was the practice, before the skin was closed, to fix the heel flap to the end of the stump with two to four deep, heavy sutures. Later, this step was discontinued although it served a useful purpose in insuring against median displacement of the heel pad.

In absolutely clean cases, in which complete hemostasis had been secured, drainage was omitted. When there had been an open wound before amputation, two rubber drains were used.

FIGURE 247.—Short stump of foot typical of type of injury in which Syme amputation was most often performed. (Left) Lateral view of stump. (Right) Anterior view. Note coverage of extensive soft-tissue defect with skin graft, a procedure that practically ruled out the possibility of below-knee amputation.

Lateral projections of skin (dog ears) were never trimmed. Experience had shown that if they were trimmed, the heel flap had a tendency to become devitalized. They disappeared spontaneously, later, after a compression bandage was used.

This bandage consisted of two 4-inch cotton elastic bandages applied over the dry gauze dressing that covered the wound. It was most important that, while the compression bandage was being applied, the heel flap be held in the center of the long axis of the leg. When this precaution was taken, adhesive strips were not necessary to hold the flap in position. All postoperative dressings were applied with the knee in extension, to avoid discomfort that might be associated with this movement during convalescence.

Postoperative management.—The standard postoperative regimen was followed in all cases, in addition to certain special measures. Elevation of the leg was practiced until the sutures were removed. A bed was used whose whole lower portion could be elevated, and the leg was further elevated on pillows. The knee was kept in extension, with just enough flexion for comfort. The bed served the purposes of a splint, and no other was required. The patient was not allowed to turn on the side on which the amputation had been performed, as a further precaution against displacing the heel flap medially.

The stump was dressed 24 hours after operation. If it was dry, one of the drains was removed. Otherwise, both were left in place for as long as

necessary, sometimes up to 7 days. Dressings were usually changed every 48 hours until the drains were removed; then, the wound was not dressed again until the sutures were removed, about the 14th day. The stump was kept tightly wrapped to the knee in cotton elastic bandages for 3 weeks after operation.

Prostheses.—At the end of this period, a temporary walking pylon was applied, preferably a nonpadded plaster including a crutch-tip extension (fig. 249). The patient used crutches for the first week after weight-bearing was instituted. Therefore, he put his full weight on the pylon, without other support. At the end of another 4 weeks, a plaster mold of the stump was made and the pylon then applied was worn, with active weight-bearing, until the permanent prosthesis was ready for use.

The permanent prosthesis was similar to the type used in the Canadian Army (fig. 250). It consisted of a foot of the conventional type, an ankle joint, a leather socket, and steel side bars that converged at the bottom of the socket to join the ankle joint mechanism. The leather socket was riveted to the steel bars.

During the latter part of the war some amputation centers developed individual types of prostheses for the Syme stump in their own shops. They were lighter than the standard artificial limb and were very satisfactory from the standpoint of function. A technician at Thomas M. England General Hospital, Atlantic City, N.J., designed a bedroom slipper (fig. 251) that was made by the patients in the occupational therapy section, with materials supplied by the artificial limb shop.

No patient was discharged from the hospital until he had been satisfactorily fitted with a prosthesis and had been trained to use it. At this time, his stump met all functional criteria, which included:

1. Good circulation and nerve supply.
2. Freedom from pain and tenderness.
3. Absence of scars that were painful or that made the use of a prosthesis difficult.
4. Absence of redundant tissue.
5. Ability to tolerate full end-bearing, with or without a prosthesis.
6. Ability to be fitted in the conventional manner, with no apparatus above the knee.

Section II. Amputations Below the Knee

The almost 7,000 amputations of the leg in World War II represented the highest regional incidence of amputations in either the upper or the lower extremity.

STATUS OF RETURNED CASUALTIES

Except for a small number of casualties, chiefly from the Mediterranean theater, who had undergone delayed primary wound closure in the

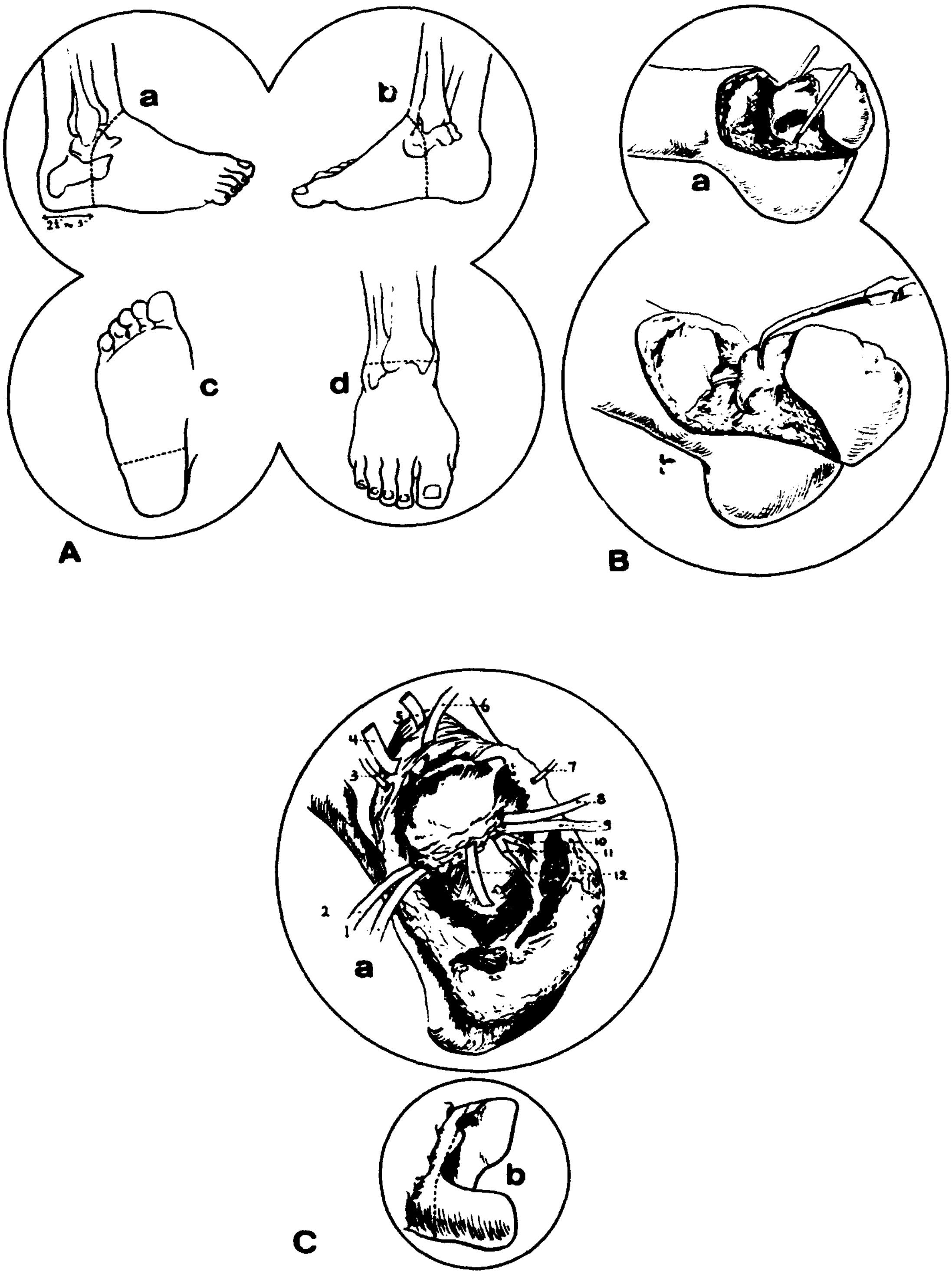

FIGURE 248.—*See opposite page for legend.*

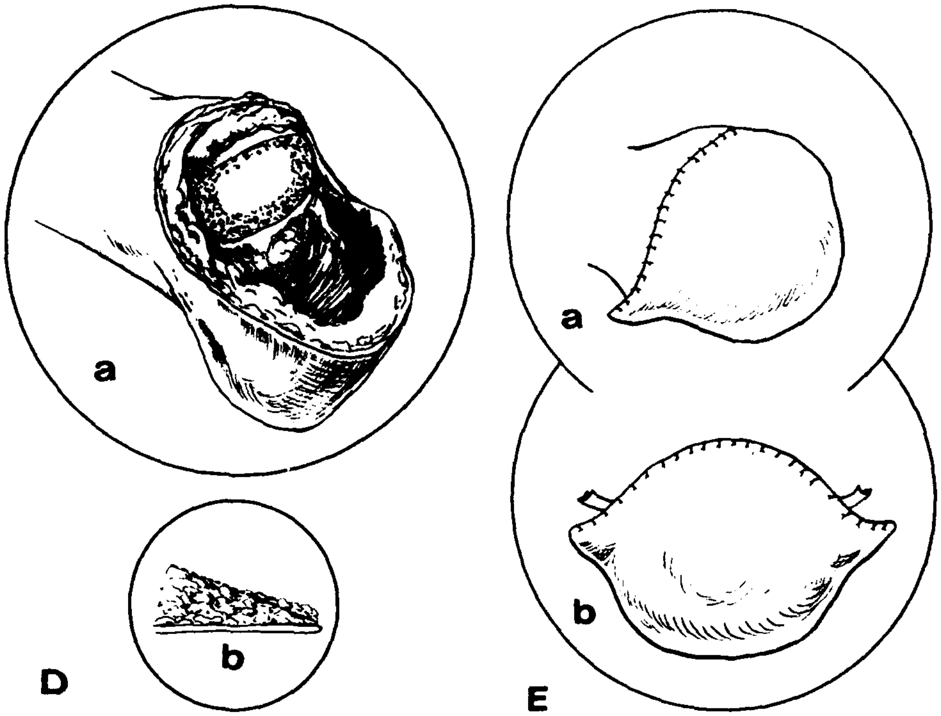

FIGURE 248.—Technique of Syme amputation. A. Incision begun across anterior aspect of ankle joint (a), extended downward and curved in front of tip of internal malleolus (b), continued downward and across sole (c), and then curved upward to meet original arm of incision (d). B. Forward dislocation of ankle by division of lateral ligaments from inside malleoli (a). Use of bone hook to facilitate extraperiosteal removal of os calcis (b). C. Exposure of malleoli extraperiosteally after removal of calcaneus and retraction of soft tissues to permit sawing off of malleoli. Management of tendons and nerves (a): Peroneus brevis (1); peroneus longus (2); cutaneous branch of superficial peroneal nerve (3); extensor digitorum longus (4); tibialis anterior (5); extensor hallucis longus (6); saphenous vein (7); tibialis posterior (8); flexor digitorum longus (9); medial plantar nerve (10); lateral plantar nerve (11); flexor hallucis longus (12). Saw line, placed as distally as possible, so that some articular cartilage would be left on end of tibia (b). D. Distal ends of tibia and fibula sawn off at lowermost levels. Tendons and nerves have been pulled down, cut at saw line, and allowed to retract. The heel flap has been debrided of all muscle, fascia, and loose strands of tissue. Unshaded area represents articular cartilage allowed to remain on end of tibia (a). Anterior edge of heel flap beveled to form wedge (b). E. Completed suture line (a). Same, with drains in situ (b). Note dog ears, left untrimmed to disappear spontaneously when compression dressing is applied.

last months of the war, all amputees with below-knee amputations arrived in the Zone of Interior with their stumps unhealed and in need of revision (fig. 252), as directed in Circular Letter No. 189, Surgeon General's Office, 17 November 1943 (*2*). The stumps that had been closed overseas, usually 5 to 10 days after open circular amputation, were generally unsatisfactory (fig. 253) because of the level of the amputation; the section of the tibia and fibula at the same level; and the presence of large ad-

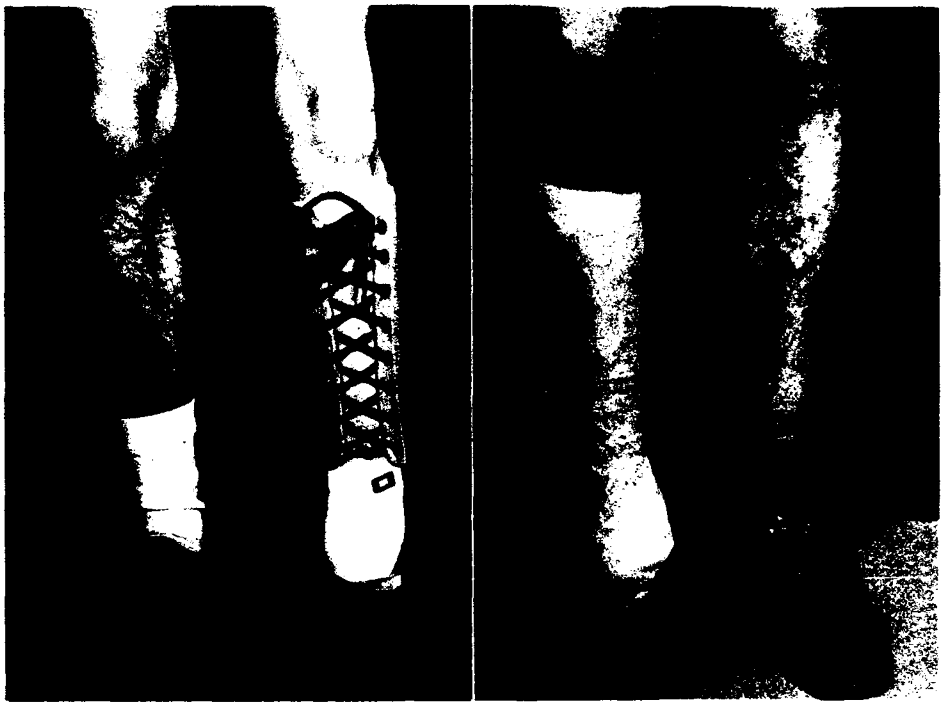

FIGURE 249.—Temporary prostheses for Syme stump. (Left) Nonpadded plaster pylon, which was applied routinely during the third and fourth postoperative weeks or as soon after operation as wound healing was complete. Full weight-bearing, without support, was possible after it had been used for a few days. (Right) Pylon used earlier in war, but discarded in favor of plaster.

herent scars and excess, redundant tissue with large dog ears. These stumps almost always required plastic revision or reamputation before a prosthesis could be fitted, which meant that no time was saved and nothing was gained to compensate for the added risks attached to early wound closure. Skin traction, not closure, was the indicated procedure; most stumps left after open circular amputation did not have enough skin available at that time for a satisfactory closure to be effected.

Factors that influenced the condition of below-knee amputees on arrival in the Zone of Interior, and also determined the treatment there, were the initial site of amputation, the efficiency of traction used during transportation, the length of time en route, and the presence or absence of soft-tissue infection and osteomyelitis.

The choice of the primary amputation site had much to do with the condition of the stump when the amputee reached a Zone of Interior hospital. Healing was more rapid at the junction of the lower and middle third of the leg (fig. 252) than in the distal fifth or when disarticulation was done at the ankle joint. The timelag between primary surgery and reamputation or other definitive surgery was, therefore, shorter.

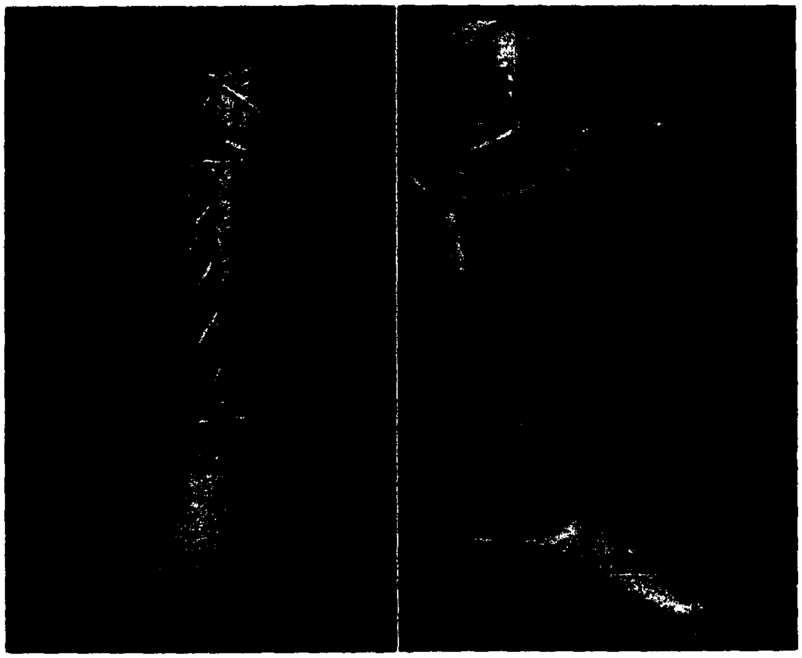

FIGURE 250.—Permanent Syme prosthesis (Minneapolis Artificial Limb Co.). (Left) Anterior view. (Right) Medial view.

For ambulatory patients, amputation through the fracture site might save bone length, but if infection had occurred, problems were greater than after open circular amputations performed just above the fracture site.

The most commonly used form of transportation traction in below-knee amputations was a plaster cast extending to the groin and applied with the knee in slight flexion to prevent rotation of the cast. Skin traction was accomplished by the use of either adhesive strips or stockinet applied with some adherent and attached by an elastic cord to a wire loop that extended from the cast beyond the end of the stump (fig. 254).

For bed patients, the best results from traction were obtained during transportation by continuous skin traction with some modification of the Thomas splint. The ring of the splint was fitted against the ischial tuberosity, and the stump was sometimes incorporated in plaster around the bars of the splint.

Better results were obtained when the knee was placed in extension for transportation. When it was immobilized in considerable flexion, it was usually difficult later to obtain complete extension. Flexion deformities were unusual in below-knee amputations when traction had been continuous and efficient.

When amputees were transported by air, traction was usually intact and in good condition on their arrival. When transportation had been prolonged, as it usually was by water, the efficacy of traction was often

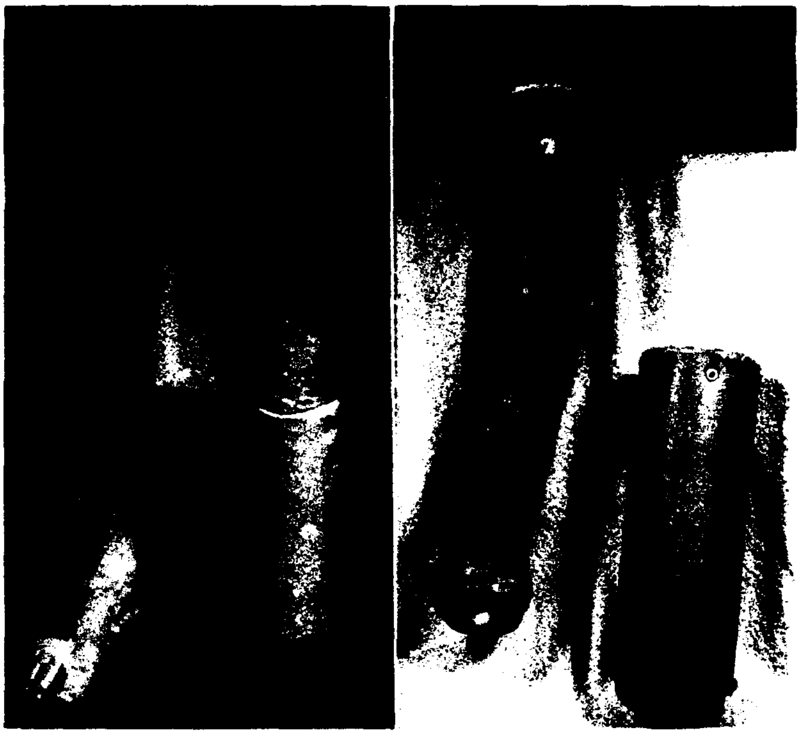

FIGURE 251.—Bedroom slipper for Syme amputees devised at Thomas M. England General Hospital Amputation Center, Atlantic City, N.J. (Left) Stump to be fitted, slipper. (Right) Slipper in use.

nullified by atrophy of the thigh muscles, by slippage of the plaster cast or adhesive tape, or by loosening of the elastic cord.

Terminal osteomyelitis of the tibia or fibula was observed in many stumps that had required extensive soft tissue drainage overseas because of *Bacillus welchii* infection. The bone was exposed in some of these cases, with resulting necrosis and terminal infection, including ring sequestra and sinuses. Preliminary operative procedures were often necessary before definitive surgery could be undertaken.

IMMEDIATE MANAGEMENT IN ZONE OF INTERIOR HOSPITALS

A review of the records of the amputation centers showed that almost every amputee who had undergone open circular amputation of the leg required revision of the stump or reamputation before a prosthesis could be fitted successfully, whether or not delayed primary wound closure had been carried out overseas.

On the average, the timelag between primary amputation overseas and definitive surgery in the Zone of Interior was 8 to 10 weeks, and at-

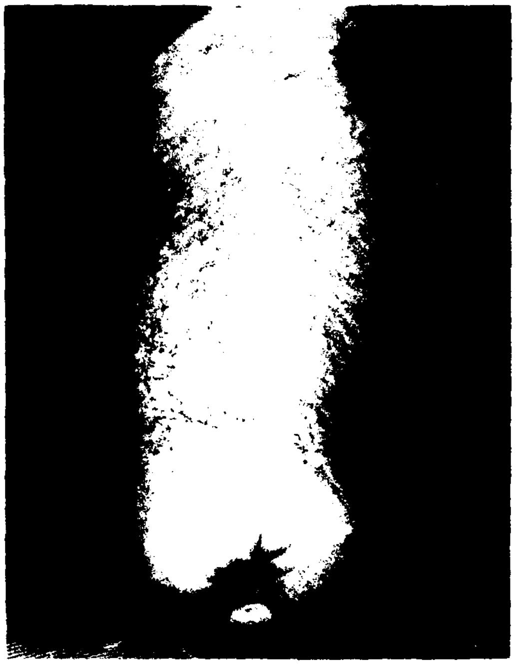

FIGURE 252.—Healing below-knee stump after open circular amputation at junction of middle and lower thirds of leg. Healing occurs more readily at this site than at a lower level.

tempts to shorten the interval by such procedures as skin grafts, whether split thickness or flap, were seldom successful (fig. 255). Indeed, attempts to expedite healing by this method produced stumps that were not suitable for fitting prostheses and that were more difficult to revise than stumps that had been allowed to heal under continuous traction. The coverage that resulted from skin grafting was never tough enough to stand up under a prosthesis, and the necessary revision of the stump required extensive undermining of flaps and, as a rule, sacrifice of considerable bone length.

Plastic revision or reamputation of the stump could be undertaken safely only when certain criteria had been met (figs. 256 and 257):

1. When active infection had been controlled, terminal edema had subsided, and healthy granulations were present.
2. When roentgenographic examination showed the bone ends to be healthy.
3. When sufficient normal skin was available for closure over the stump without tension or shortening of the bone.

Early in the war, attempts were made at several of the amputation centers to determine by colony count when infection had disappeared. The plan proved unreliable as well as impractical and was soon discarded.

Complete healing of the stump was the desideratum before definitive

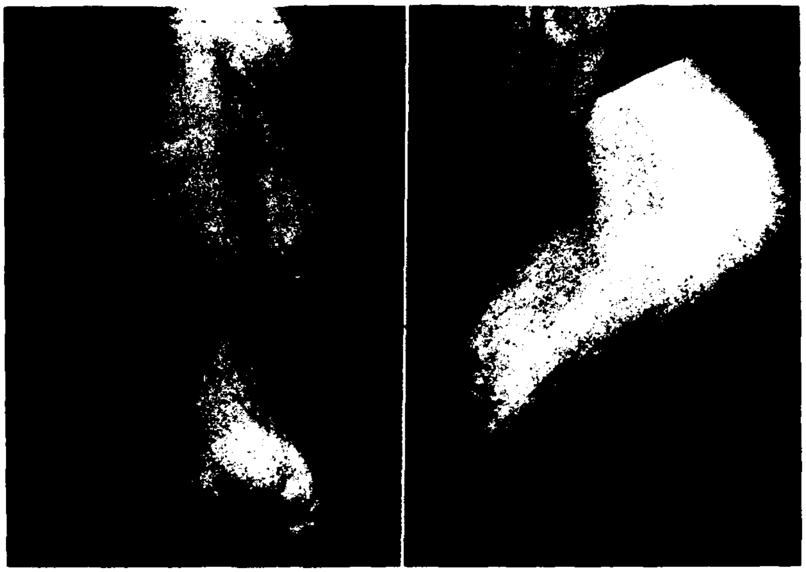

FIGURE 253.—Below-knee (right) stump in which delayed primary wound closure had been done overseas. (Left) Anterior view, showing condition of stump when amputee arrived in Zone of Interior. (Right) Lateral view after reamputation. This operation was performed early in the war, when stumps were somewhat longer than was customary later.

surgery was undertaken, but it was not always practical to wait until it occurred. In such cases, the problem was usually persistent active infection of the terminal portion of the bones, with sequestration, most often of the ring type, at their ends. Such infections tended to be intractable, in spite of correct treatment in the form of local measures and penicillin therapy, and the most practical plan was often early open reamputation, followed, as soon as possible, by plastic repair. When osteomyelitis of the shaft of the fibula was extensive, total removal of the bone was usually the wisest plan.

PREOPERATIVE ROUTINE

When amputees were received at Zone of Interior amputation centers, stumps in which granulating areas were still present were treated by appropriate dressings for 24 to 48 hours, to clean up the secretions and crusts that had accumulated during transportation. When cellulitis was present, the most effective treatment was the application of wet packs of a saturated solution of boric acid. When the packs were covered with oiled silk or cellophane to prevent evaporation, it was necessary to change them only once a day. This method also relieved the pain sometimes associated with the cellulitis.

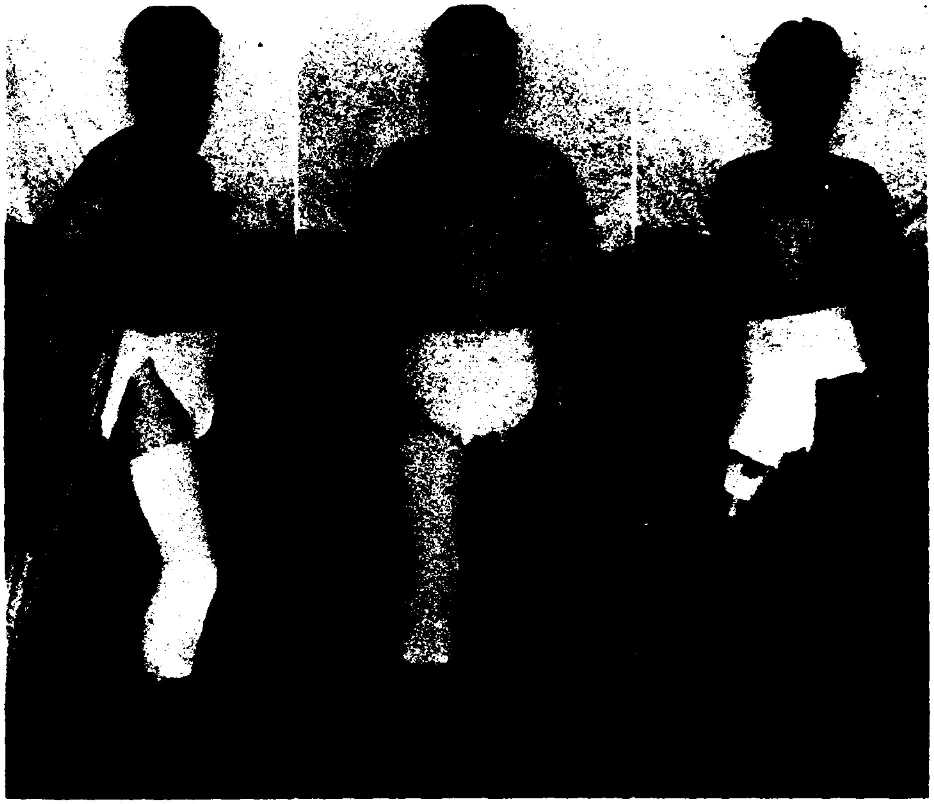

FIGURE 254.—Fixed elastic traction for transportation in below-knee amputations. A suitable cast was applied to the stumps with heavy wire, or a wire ladder splint was incorporated in it. Traction was maintained by a rubber elastic cord fixing the stockinet to the wire, which extended well beyond the stump end. Note position of knee.

Wet dressings were continued until drainage had ceased. Then a simple petrolatum-impregnated dressing was applied and traction was instituted at once, with the patient recumbent in bed and the stump elevated. This practice was mandatory. The desired results—healing, decreased local edema, and circulatory improvement—could not be accomplished with the patient ambulatory.

Amputees received with flexion deformities of the stump were instructed in intensive quadriceps setting exercises while they were still in bed. These exercises, combined with constant skin traction, corrected most deformities. Those which did not respond were handled by wedging plasters. In the few cases in which complete extension of the joint was not obtained by these means, posterior capsulectomy was performed, with section of the hamstrings. If the condition was really irreparable and satisfactory movement and prosthetic fitting could not be obtained, amputation was carried out above the knee.

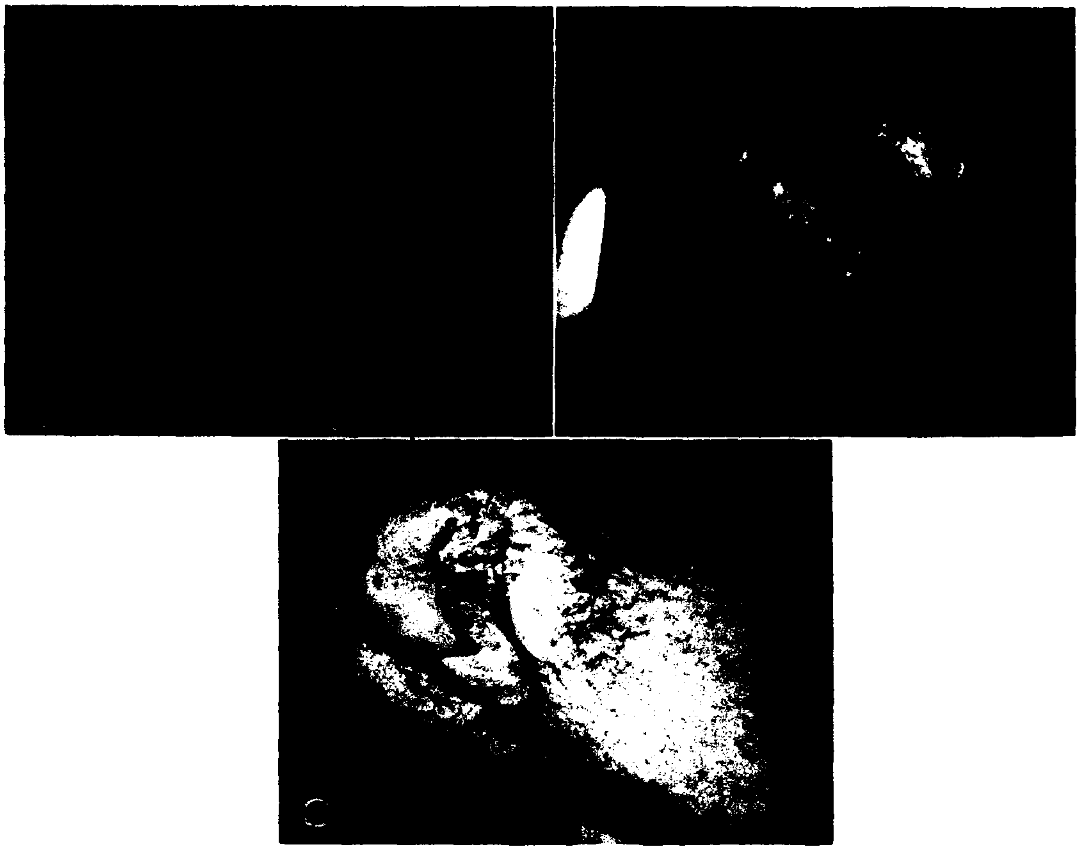

FIGURE 255.—Stump after open amputation and application of split-thickness graft in effort to hasten healing. Later in the war, it was found that constant skin traction accomplished the desired results more efficiently than skin grafting. A. Lateral view of stump. B. End view. C. Stump ready for revision, which will require moderate sacrifice of length.

Early in the war, sulfonamides were used before and after definitive surgery. When penicillin became available in sufficient quantities for general use, it was prescribed routinely by the parenteral route. While quantities were still limited, it was given only in cases of extensive cellulitis or osteomyelitis in which cultures were positive for penicillin-sensitive organisms.

DEFINITIVE SURGERY

Plastic Repair

Plastic repair of the below-knee stump left after open circular amputation required careful planning. Only enough scar tissue, granulation tissue and bone were excised to permit closure of the subcutaneous tissue and skin without undue tension. The precise location of the final scar,

FIGURE 256.—Below-knee stump after open amputation, with clean, healthy granulations. A stump in this condition could be safely reamputated at the site of election. (Top) Lateral view. (Bottom) Medial view.

though preferably slightly posterior, was of little importance if primary healing was obtained.

The anterior crest of the tibia was beveled and the fibula was resected from 1 to 2 inches proximal to the tibial section. If the stump was less than 3 inches long, the entire fibula was removed. It was also removed routinely if it was deformed and was likely to be unduly prominent after operation.

To secure smooth approximation of the skin margins, it was usually necessary to undermine the skin flaps for a considerable distance. The flaps could be anterior and posterior, or one could be anterolateral and the other posterolateral. Subcutaneous sutures were not generally used, and deep stay sutures were also considered unnecessary.

At the amputation centers at Bushnell General Hospital, Brigham City, Utah, and Lawson General Hospital, Atlanta, Ga., fine, nonabsorbable

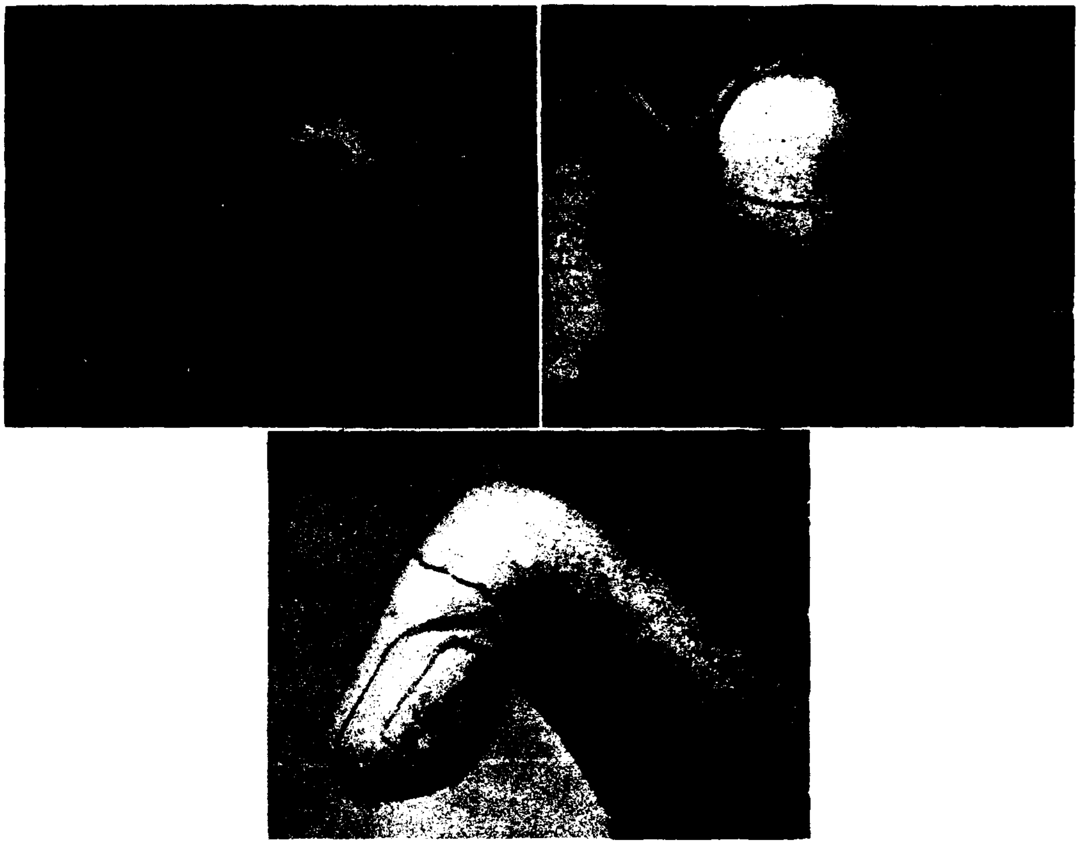

FIGURE 257.—Ideal below-knee stump: optimum bone length 5 to 7 inches; scar slightly posterior and nonadherent; fibula 1 to 1½ inches shorter than tibia; crest of tibia beveled and tapering; no excess muscle posteriorly. A. Medial view of stump. B. Anterior view. C. Lateral view.

sutures were used in revision operations and drainage was often omitted. It was almost impossible, however, to secure a completely dry postoperative field, even though all obvious bleeders were ligated before the skin flaps were closed. Rubber tissue drains were, therefore, usually inserted near the ends of the incision and kept in place for 1 to 3 days.

Reamputation

Early in the war it was thought that a stump length of approximately 5 to 7 inches was ideal. It was also thought that stumps only 2 inches long, measuring from the medial hamstring, could not be fitted satisfactorily. Further experience changed these concepts and it became the unanimous opinion at all amputation centers that the ideal length for a below-knee stump was more nearly 5 inches of bone length, measured from the articular surface of the tibia (fig. 257). A stump of this length had a number

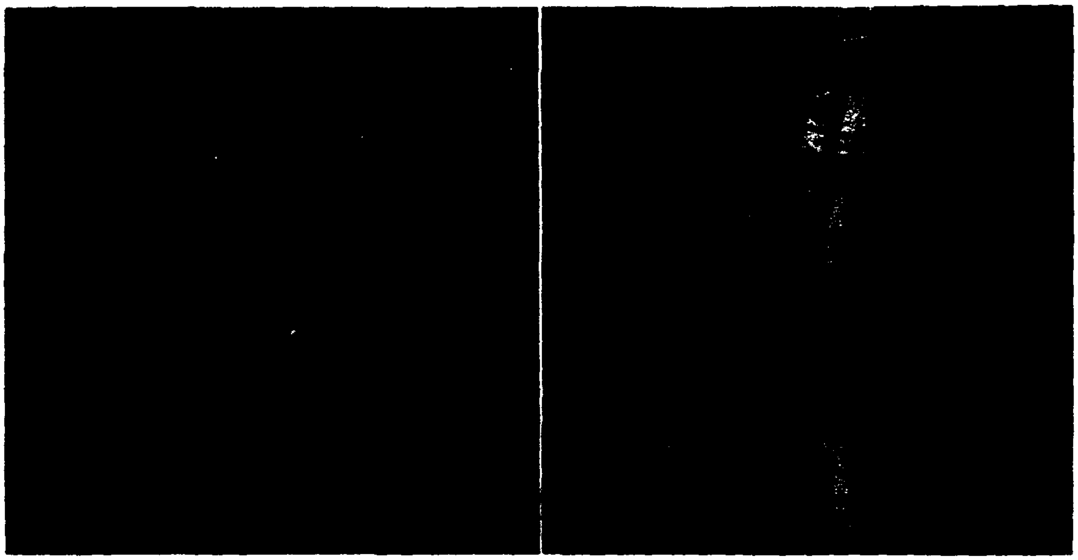

FIGURE 258.—Below-knee (left) stump after amputation at junction of middle and lower third of leg. Note excessive length, which is of no value and really disadvantageous. A stump of this kind was difficult to fit with a prosthesis and was likely to break down and ulcerate at the end. (Left) Lateral view. (Right) Anterior view, with prosthesis in place. Note the increased diameter of the affected skin, as compared with that of the intact leg, as the result of the excessive length of the stump.

of advantages: It was comparatively free of circulatory disturbances. It was easily fitted with a standard prosthesis, for whose activation it provided satisfactory leverage. It did not require an increase in the diameter of the affected shin, which was required with longer stumps and which made the two extremities asymmetrical (fig. 258). Finally breakdowns in stumps of this length were minimal.

Even very short stumps could be fitted satisfactorily. A stump with as little as 1 to 1½ inches of bone length could be handled by excision of the fibula, section of the medial hamstring, and excision of the redundant gastrocnemius and soleus muscles (fig. 259).

The posterior fascial flap (Kirk) technique, which was employed at most amputation centers, had as its essential feature bringing the posterior fascia over the end of the tibia, without excess muscle tissue. The soft tissues and bones were handled by the method just described.

A modified reamputation technique employed at Walter Reed General Hospital, Washington, D.C., and England General Hospital gave excellent results. It utilized anterior and posterior flaps consisting only of subcutaneous tissue and skin. All muscles were sectioned at the site of the saw cut. No attempt was made to bring the posterior fascia over the bone and suture it there. Drainage was established through a stab wound in the posterior flap.

Postoperative management consisted of standard measures. Drains

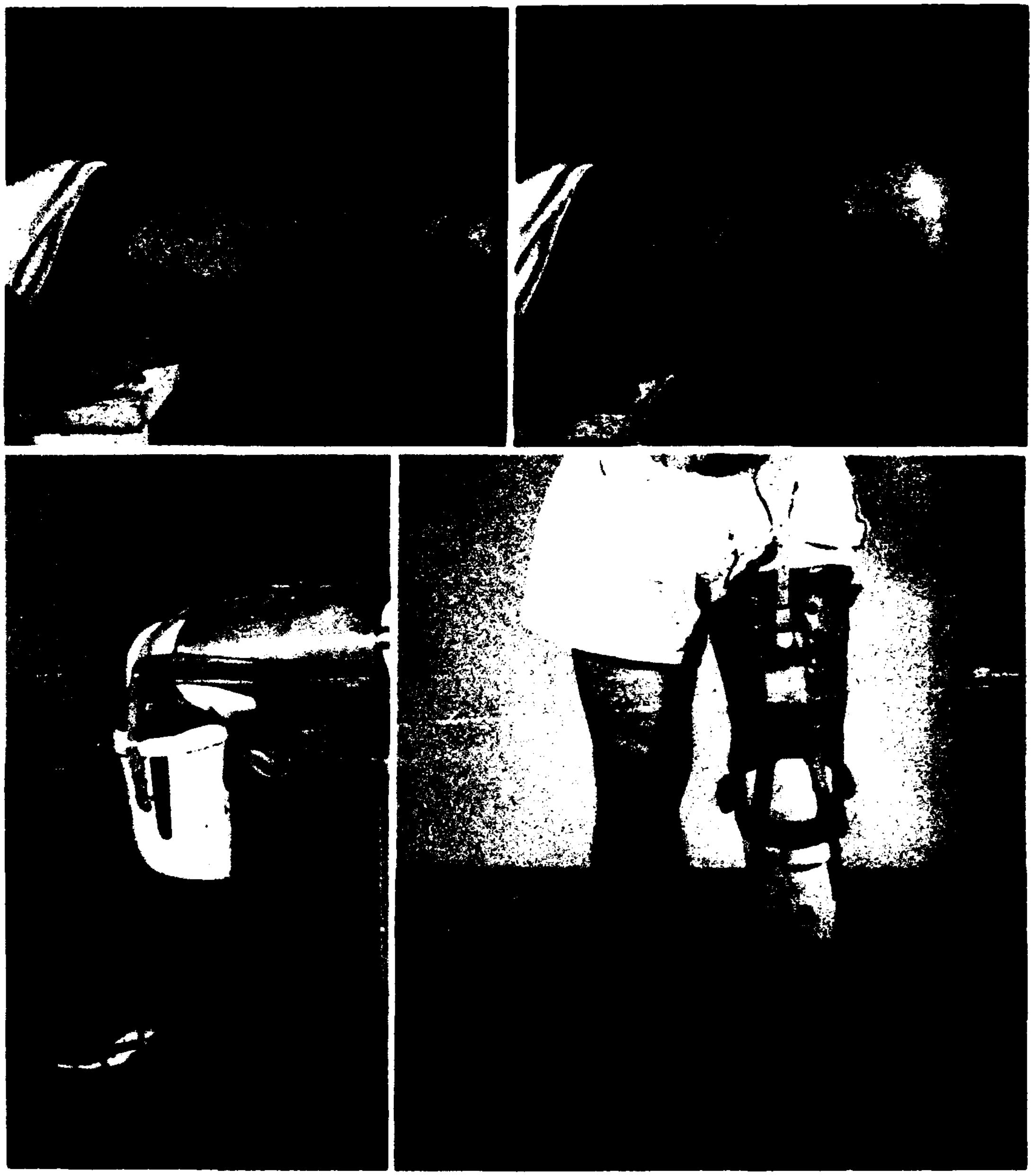

FIGURE 259.—Short below-knee stump, with bone length of 1½ inches. The functional length of this stump was increased by section of the medial hamstring tendons and removal of the fibula. A. Medial view of stump. B. Same, with knee flexed. C. Lateral view, with knee flexed and provisional prosthesis in place. D. Anterior view with patient standing.

were removed at the first dressing, usually 48 to 72 hours after operation. Skin traction was instituted for several days only if there was an undue amount of tension on the flaps. Usually immobilization in plaster, with the knee in extension, was maintained until the sutures were removed, about the 12th day. The stump was kept firmly bandaged with an elastic bandage

throughout the subsequent postoperative period, to reduce edema and shrink the tissues. The patient was kept recumbent until all evidences of local reaction had subsided. Complications, which were infrequent and usually minor, were handled according to the circumstances of the special case.

PROSTHESES

In the ideal stump ready for fitting (fig. 257), the fibula was shorter than the tibia. The anterior aspect of the tibia was beveled. The ends of the bones had been treated by sharp section with minimal disturbance of the periosteum and endosteum. A conical shape had been achieved by removal of redundant tissue in the posterior portion of the stump. The wound was well healed. The stump was well shrunken, nontender, and without adherent scar tissue. The surgical scar was so placed that it would not have to tolerate direct pressure from the prosthesis. The activating muscles of the stump were fully functional. There was no flexion deformity in the knee joint.

Development of Socket

When prosthetic shops were authorized at amputation centers in May 1943 (p. 883), the fiber limb was used exclusively as a provisional prosthesis. Patients were fitted with this limb as soon after revision or reamputation as the condition of the stump permitted. If shrinkage of the tissues occurred, the original socket was replaced by a smaller one.

At the beginning of U.S. participation in the war, sockets were constructed of leather molded over plastic models of individual stumps. Although these sockets were reasonably satisfactory functionally, they had several drawbacks: Their fabrication was time-consuming. They tended to deteriorate in use, particularly in damp climates and if the wearer perspired excessively. An occasional socket lost its shape because of softening of the leather.

To find a more suitable material than leather, tests were carried out with a number of substitutes, of which Celastic, manufactured by E. I. du Pont de Nemours & Co., proved the most satisfactory. It could be shaped easily over the model. It dried rapidly. If shrinkage of the stump occurred, it was not necessary to construct a new socket; an additional layer of Celastic could be applied inside the original socket. Celastic sockets proved highly satisfactory in dry, warm climates, but in wet climates they softened as the result of atmospheric conditions, and over long periods in such climates, they did not prove satisfactory. Deterioration was particularly troublesome at England General Hospital. which was situated on the seashore.

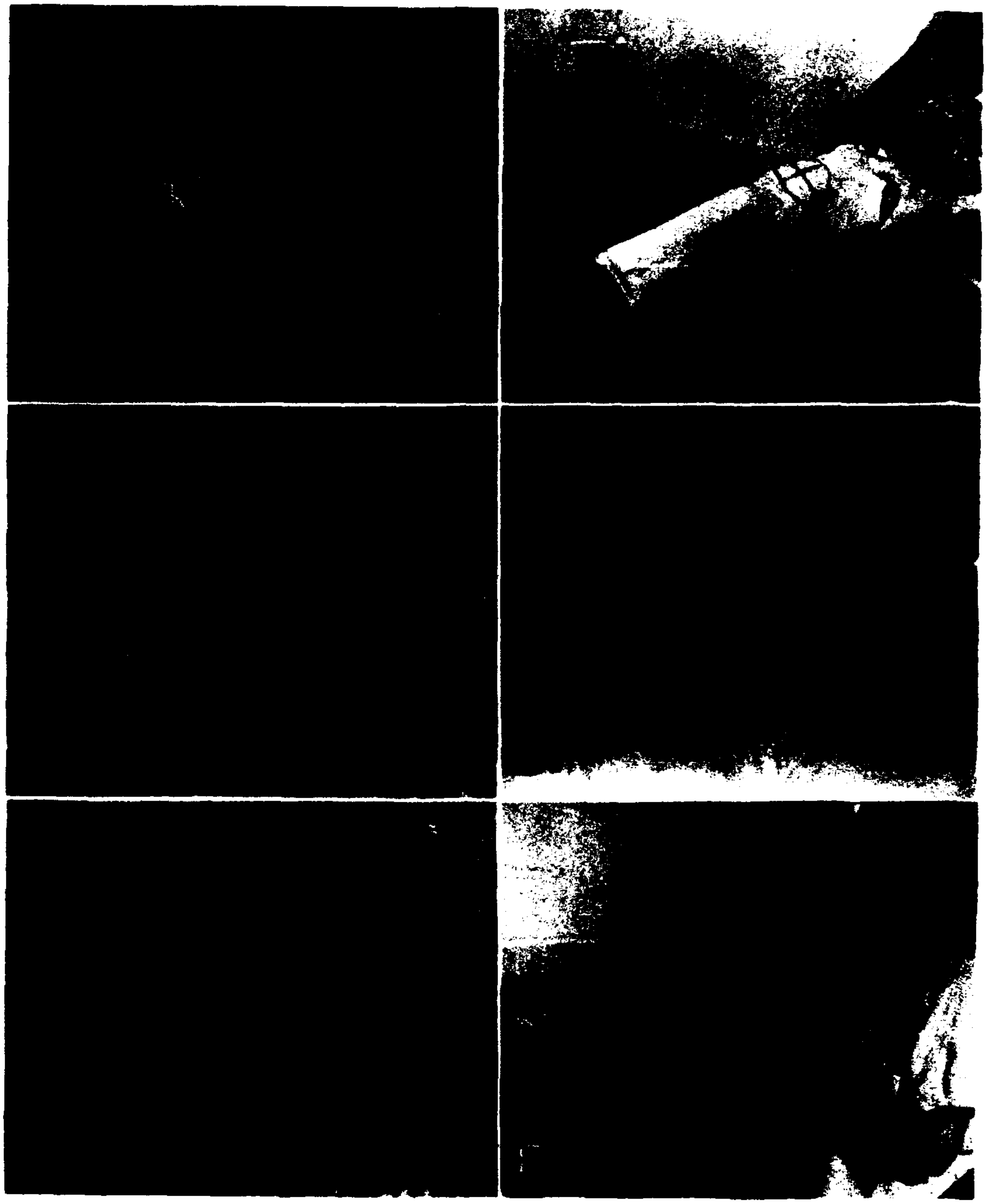

FIGURE 260.—Construction of prosthesis for below-knee stump. A. Application of cardboard cuff to end of stump and of felt over pressure points on leg. B. Application of stockinet. C. Application of plaster. D. Formation of plaster model of stump. E. Model of stump on mandrel. F. Wrapping of plaster model with gauze bandage by one technician while another impregnates bandage with Bakelite according to technique developed at Bushnell General Hospital Amputation Center, Brigham City, Utah.

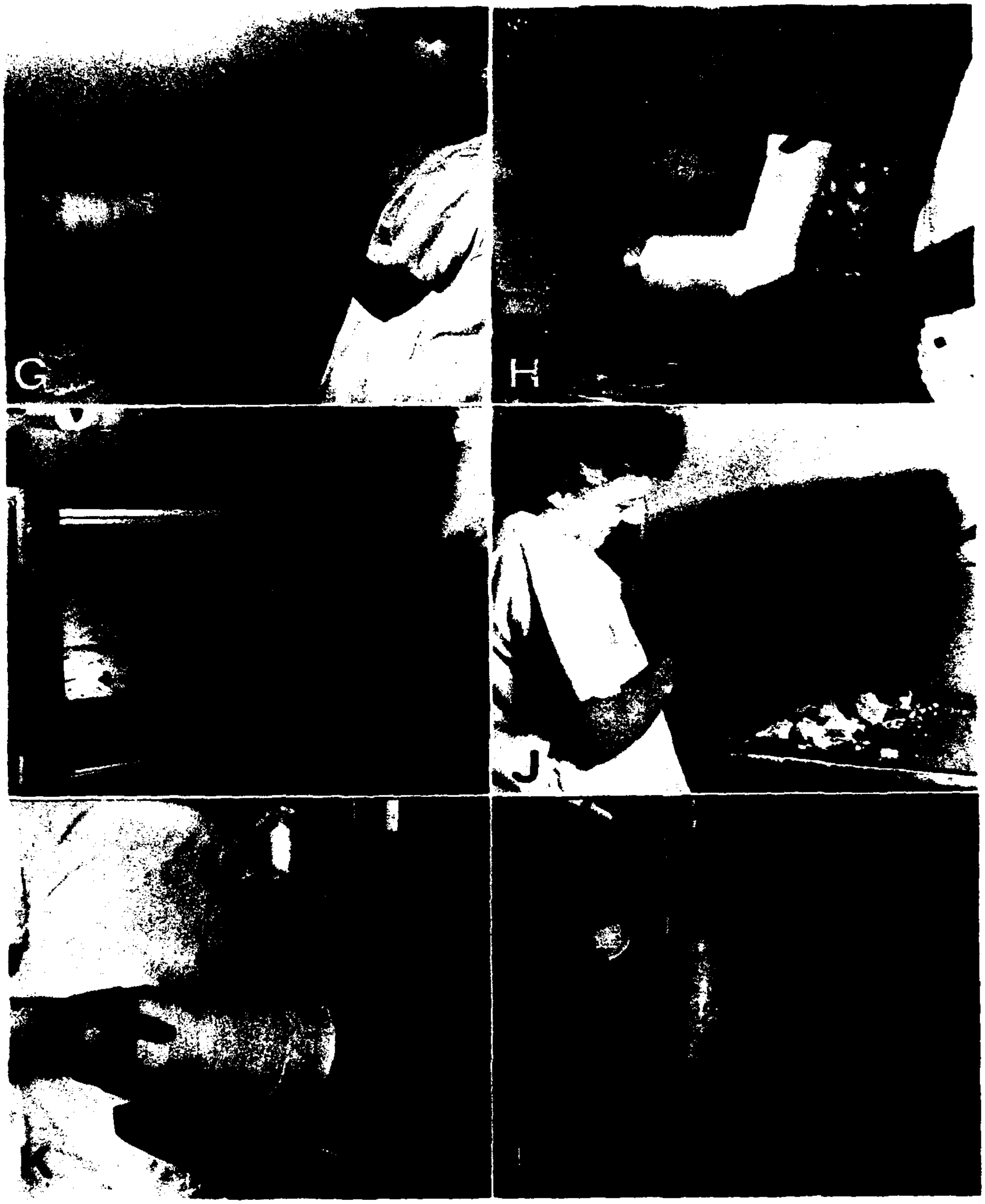

FIGURE 260.—Continued. G. Covering of model and plastic socket with polyvinyl alcohol sheet. H. Application of pressure to socket by elastic bandage. I. Baking of plastic socket at 225° F. for 1 hour. J. Removal of plastic model from new Bakelite socket. K. Sawing socket against center of knee joint. L. Shaping shoulder of prosthesis.

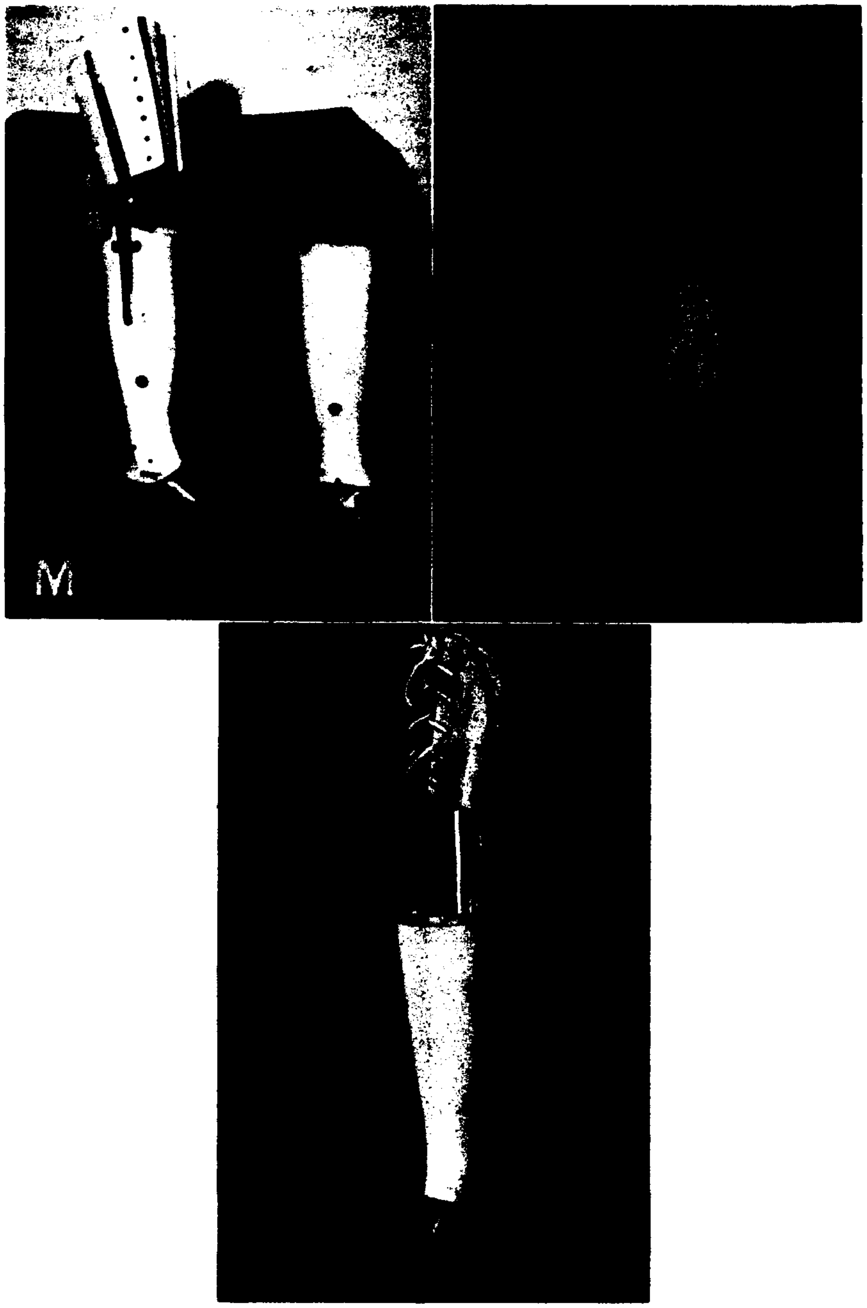

FIGURE 260.—Continued. M. Shin section before and after assembly. N. Plastic socket before insertion in shin section. O. Prosthesis assembled.

Bakelite sockets were developed at the amputation center at Bushnell General Hospital, by Mr. Mike Nagy of the Northrop Aircraft Corp. They were made available to other amputation centers in the middle of 1945.

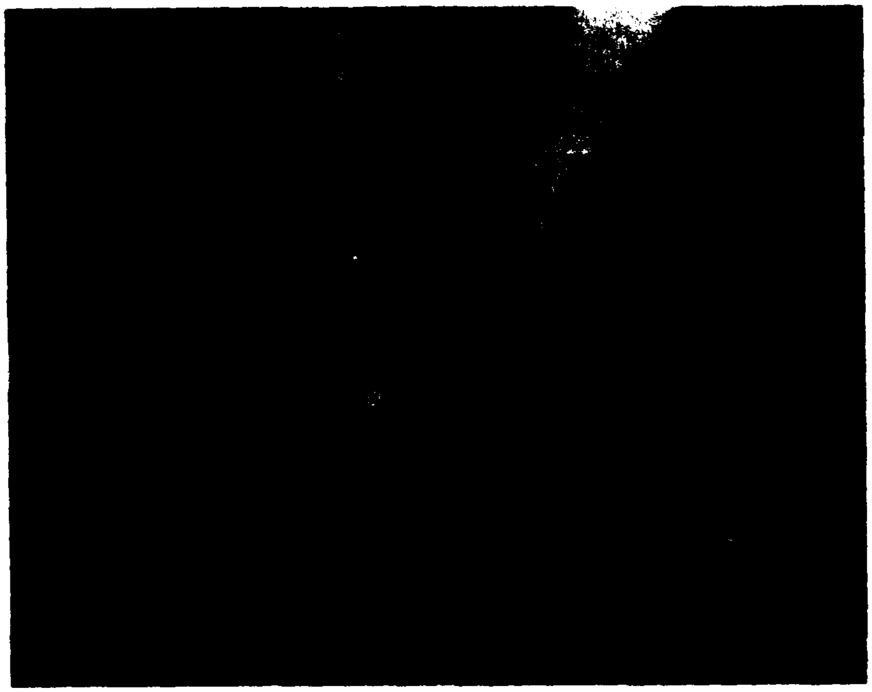

FIGURE 261.—Muley type below-knee prosthesis. Knee joints and thigh cuff are omitted and the prosthesis is attached only by a simple band above the knee.

Fabrication of the Individual Prosthesis

As soon as the stump was considered ready for a permanent prosthesis, the amputee was sent to the artificial limb shop, equipped with a measurement card and a new pair of shoes. The steps of fabrication of the prosthesis, which were handled by different sections of the shop, are described in figure 260.

When the assembled leg was ready for the initial fitting, the thigh corset was fixed temporarily to the knee brace. If the fitting was satisfactory, the temporary screws were removed and the thigh corset and shin section were riveted to the appropriate portions of the hinged knee joint. The prosthesis was then refitted and checked carefully for alinement, and adjustments were made as necessary.

The patient was followed closely for several days after the initial fitting, for the inner lining of the plastic socket usually required further smoothing.

There were some variations from the routine just described. Some below-knee stumps were fitted with a so-called Muley prosthesis, which required only a simple strap above the knee (fig. 261). A slip socket was occasionally used with the below-knee prosthesis. This socket (fig. 262) remained in contact with the stump while it (the socket) moved slightly

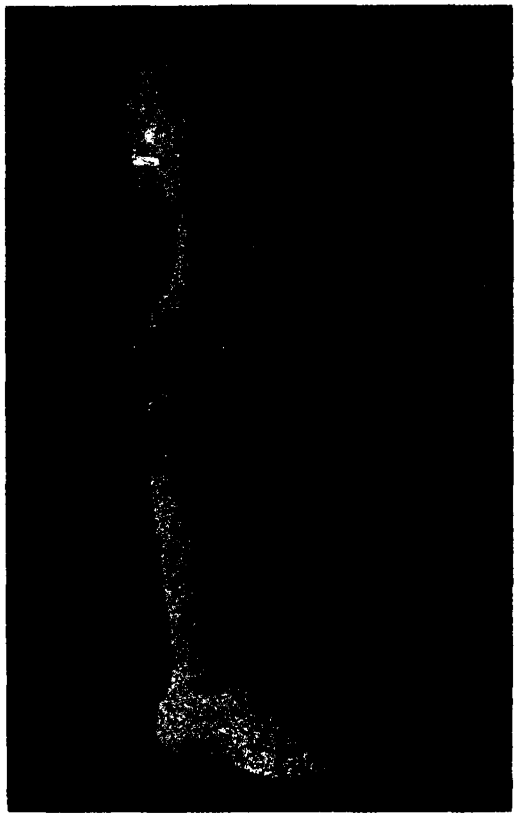

Figure 262.—Below-knee prosthesis with slip socket, which remains in firm contact with stump but moves slightly with each step in relation to outer socket or shin section. This socket, of molded leather, is suspended from the thigh cuff by elastic straps. The outer socket is adjustable by posterior leather lacing. (Winkley Artificial Limb Co. Prosthetic and Sensory Aids, Veterans' Administration.)

upward and downward in the shin piece. A rigid socket was considered superior in most cases.

Below-knee stumps which did not tolerate full weight-bearing could be protected by an ischial-bearing below-knee prosthesis (fig. 263). In this type of fitting, the weight was borne on the ischial tuberosity, as in the above-knee fitting, while the knee and the below-knee stump activated the prosthesis and provided a normal gait.

Before the patient was discharged, he was sent to the braceshop for a final check of fit and alinement of the prosthesis. If it was satisfactory, he was given a clearance. At this time, the artificial leg was painted and the plastic socket was bonded into the shank of the prosthesis.

FIGURE 263.—Below-knee stump with slip socket and ischial-bearing type of prosthesis. Shin section is of fiber. Weight-bearing is taken on ischial tuberosity, which protects the stump. Front and rear views with prosthesis in place.

Section III. End-Bearing Amputations at or Above Knee

GENERAL CONSIDERATIONS

The approximately 4,500 amputations above the knee performed in World War II represented about 30 percent of the total number of amputations. They were divided into two groups, according to the level at which the limb was removed:

1. The level at which a partial or complete end-bearing[3] prosthesis could be used. Amputations that produced a satisfactory end-bearing stump ranged from disarticulation of the knee to progressively higher levels of transcondylar and supracondylar amputation performed at a level at which broad cancellous bone, with proper soft-tissue coverage, permitted weight-bearing on the end of the stump.
2. The level at which an end-bearing prosthesis could not be used because the tubular bone in the stump tended to cut through the overlying soft tissues. Stumps in this group required ischial-bearing prostheses; the body weight was borne on the ischium and the stump activated the prosthesis.

When suitable skin traction had been applied promptly after open circular amputation and had been maintained throughout transportation, amputees in this group arrived in good condition. Their stumps were well

[3] Also commonly referred to as knee-bearing.

healed and their circular scars were small and adherent, with radiating folds extending out into the surrounding soft tissue. All that was necessary in such a stump was to excise the scar, undermine skin flaps, and effect closure with a minimum of tension. It was not always necessary to sacrifice any bone length.

When skin traction had been inadequate or inconstant, or had not been employed at all, primary healing was unsatisfactory, just as it was under similar circumstances in below-knee amputations.

DISARTICULATION AT THE KNEE

It was originally believed that, because of the bulbous shape of the resulting stump, disarticulation at the knee joint would not be a satisfactory procedure from the prosthetic point of view. Experience did not bear this presumption out. If skin coverage was good, these stumps could be fitted on the same principles as other end-bearing or bent-knee stumps, and they proved excellent functionally.

Disarticulation was the procedure of choice when a flexion deformity of the knee or retraction of soft tissues in a short below-knee stump made reamputation at a higher level necessary before a prosthesis could be fitted. Disarticulation was indicated also if infections of the bone in below-knee stumps did not respond to treatment. It could be used only when the knee joint was not involved in the infection.

Disarticulation of the knee joint as a revision operation was performed as follows:

1. An anterior flap, as long and as wide as could be obtained, was utilized because anterior skin was almost invariably more abundant. The breadth thus provided was necessary for coverage of the wide aspects of the condyles. If the skin flap was too narrow, tension in the area of the condyles would result and impairment of the circulation would be a risk because of pressure from the prosthesis.

2. The management of the patella depended upon the preferences of the individual surgeon ard the circumstances of the special case. Some surgeons preferred to insert the patella into a mortise in the anterior aspect of the femoral condyles where, after it became fused, it would bear part of the body weight. Others preferred to leave the patella loosely in place, because it was found that it would retract upward out of the way of the prosthesis. When the below-knee stump was very short and there was not enough skin available for the flap, extra length was provided for it by removal of the patella.

3. The most important step in disarticulation at the knee was fixation of the posterior to the anterior tendinous structures by cutting the patellar tendon as close as possible to the tibial tubercle.

4. The anterior flap consisted of the patellar tendon, the anterior deep fascial layer of the thigh, the skin, and the subcutaneous tissue, which were preserved as a single structure.

5. The first step in the creation of the posterior flap was the separate removal of each hamstring muscle from its insertion. Each muscle was clamped separately, to prevent its slipping back into the thigh. After all muscles and nerves had been cared for, each hamstring muscle was attached separately to the patellar tendon in the

intercondylar notch. Their attachment in this manner had two objectives, (a) to provide tissue to fill the intercondylar notch, so that no hollow space would remain after healing, and (b) to avoid muscle tension, so that the skin flap would not be pulled open.

The cartilage left on the femoral condyles appeared able to bear the complete body weight without difficulty.

END-BEARING AMPUTATIONS THROUGH THE LOWER THIGH

The saw line for an end-bearing amputation in the region of the knee was through the lower femoral condyles, which are formed of cancellous bone contained in a thin cortical shell. When the bone is sectioned just above the adductor tubercle, its end presents a broad, semiquadrilateral surface suitable for end-bearing.

Since many of the amputees who required reamputation at the supracondylar level had potentially infected stumps, a supracondylar tendoplastic technique was generally employed. Under the circumstances, it was feared that the osteoplastic Gritti-Stokes operation might fail because of osteomyelitis or because of failure of union of the patella to the femur. There is only one real difference between the two procedures, that in the tendoplastic operation the patella is excised, while in the osteoplastic procedure, it is fixed to the end of the femur.

Technique.—Supracondylar tendoplastic amputation was performed as follows:

1. A long anterior flap was created, containing skin, fascia, and the quadriceps tendon. The saw line, as already mentioned, was supracondylar, through cancellous bone.
2. The anterior flap was retracted. The fascia was cut one-fourth of an inch longer than the skin. The periosteum was incised sharply at the saw line, and the bone was resected.
3. The quadriceps tendon was brought directly over the bone and secured to the fascia posteriorly with towel clamps until it was sutured.
4. Before the skin was closed, a rubber tissue drain was placed under the muscle tendon flap.
5. If the closure seemed tight because of the pull of the quadriceps tendon over the bone end, skin traction was applied for a few days.

Prostheses.—An end-bearing (knee-bearing) prosthesis (fig. 264) had the great advantage of providing the amputee with an improved sense of balance. Its principal disadvantage was that it provided only simple hinged action at the knee and not friction control.

The socket was usually made of molded leather. Its front was cut away and replaced with a tongue and laces because the bulbous stump could not be inserted into a closed, tapered socket. If full end-bearing was desired, the top of the socket was not extended to the ischial tuberosity.

A harness or suspension device was not always necessary either in disarticulation at the knee or in the bent-knee type of fitting. As a rule,

FIGURE 264.—End-bearing prosthesis used in amputation through or just above condyles, also for disarticulation at knee joint. The leather socket is laced, to admit bulbous end of stump and to allow for shrinkage of tissues. The shin section could be made of wood, metal, or plastic instead of fiber. The metal hip joint and belt were not always necessary.

however, the socket was attached to a hip joint and belt similar to the apparatus used in the ischial-bearing prosthesis. A belt could also be used, with a fork strap attached to the socket and the shin section on each side.

Section IV. Above-Knee Amputations

GENERAL CONSIDERATIONS

As pointed out earlier in this chapter, end-bearing prostheses could be fitted after amputation at the lower level of the femur, through cancellous bone, at or just above the femoral condyles. Amputations above this level, through the shaft of the femur, required ischial-bearing pros-

theses. Because of the strong contractability of the massive muscles of the thigh, conical stumps were more apt to develop after amputations at this level than after amputations of the leg or of the upper extremity. Function in thigh stumps diminished progressively after amputations at higher levels. Stump length was measured from the perineum to the end of the stump when the stump lay in full extension, parallel with the opposite thigh.

Plastic revision required after primary amputations through the thigh involved removal of little or no bone. Reamputation, however, was necessary in a number of situations:

1. Loss of soft tissue with extensive scar replacement, conditions in which the pressure of a prosthesis could not be tolerated.
2. Persistent bone infection.
3. Infection of the knee joint in a below-knee stump that did not respond to treatment.
4. Ankylosis of the knee.

Closed reamputation was deferred until it was certain that primary healing would not occur. If the proposed level of revision was close to the end of the stump, complete healing was desirable, but not essential, before secondary surgery. If the level of the proposed reamputation was well above the open stump, the operation could be performed before complete healing had occurred, with the proviso, of course, that all active inflammation had subsided.

TECHNIQUE

The ideal stump for an amputation through the femoral shaft had a length of 10 to 12 inches from the greater trochanter and was about 5 inches above the joint. If amputation was necessary at a lower level, the prosthesis required to incorporate the friction type of knee joint had a thigh piece longer than the normal thigh and a shin piece shorter than the normal shin.

The technique was similar whether the operation was performed in the lower, middle, or upper third of the thigh:

> The suture line was placed just posterior to the bone end whenever this was possible by use of skin flaps that were slightly longer anteriorly than posteriorly.
>
> A muscle flap was cut from the quadriceps group, thinned down by cutting away its inner half, brought over the bone, and sutured to the posterior muscle groups which had retracted to the saw line. Some surgeons preferred to allow the muscles to retract and closed only fascia, subcutaneous tissue, and skin over the end of the bone. A rubber tissue drain placed under the muscle flap emerged between the sutures on the outer aspect of the stump.

The extremity was elevated on pillows during the healing period and kept tightly bandaged, to reduce edema. Two 4-inch elastic bandages, sewed together end to end, were adequate for the average stump, but 6-inch

bandages were recommended for larger stumps. Each patient was taught to bandage his own stump as soon as possible. Someone had to secure the bandage for him when he made recurrent turns over the end of the stump, but he was trained to elevate his pelvis with his good leg so that the stump was held in extension when he applied the bandage to his waist. Amputees who were ambulatory and receiving physical therapy were taught bandaging in groups by the physical therapist. The application was carried out with strict attention to detail, with even pressure, and as firmly as could be tolerated without pain or circulatory interference.

PROSTHESES

Stumps as short as 2 inches measured from the crotch could usually be fitted like other above-knee amputations. When this was not possible, a prosthesis of the tilting-table type was used, just as for a hip disarticulation, with the stump flexed to 90 degrees. The usual fitting for a thigh stump was an ischial-bearing socket in which the patient sat on the prosthesis.

Thigh Section

A satisfactory thigh prosthesis (fig. 265) depended upon a socket so fitted and so alined that (1) the body weight was borne on a well-formed ischial seat and (2) the conical sides of the stump received uniform pressure and support from it, while pressure on tender points was avoided. A horizontal section of the top of the socket was somewhat triangular in shape, with the posterior, medial, and anterior surfaces forming the flattened segments. Posteriorly, the top of the socket had a broad, well-formed ischial seat medially, which extended laterally in the region of the greater trochanter, where it met the anterolateral border of the socket. The medial border of the socket was flat, to fit the perineum. The socket was hallowed anteromedially to accommodate the adductor longus tendon. As the socket extended downward, it gradually lost its triangular shape and was circular when it joined the knee.

Posteriorly, the ischial tuberosity rested on the socket, which was so fitted that the tuberosity could not sink down inside of it and the body would not lose its bony support. If the ischial tuberosity did not come down to rest on the socket, it was assumed that the socket was too small for the stump and another fitting was carried out.

In the provisional fiber limb (fig. 266), the thigh piece, which was prefabricated as an ischial-bearing socket, was adjusted for size by removing the rivets and enlarging or contracting the circumference of the socket as indicated. The disadvantage of this method was that alteration of the size of the circumference tended to distort its shape. If adjustments

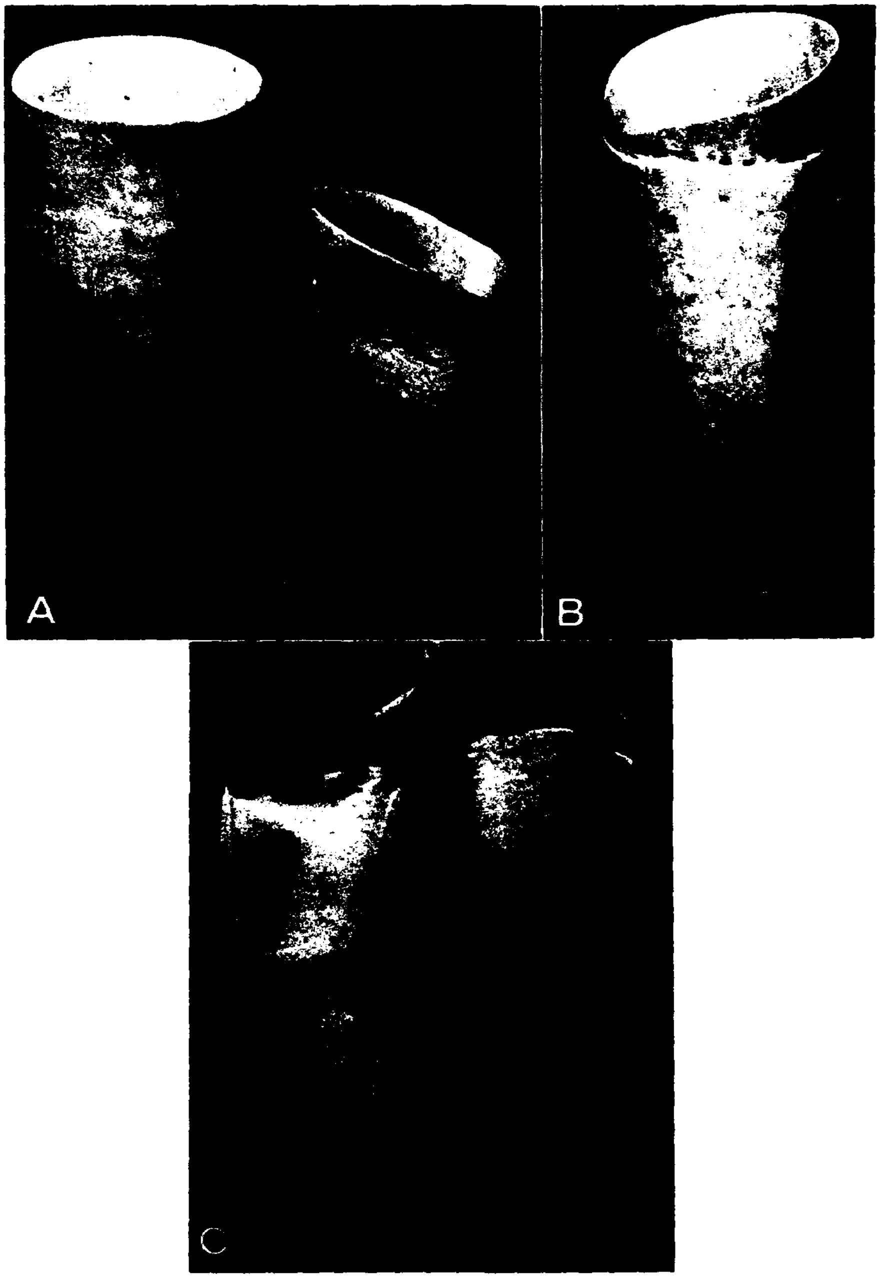

FIGURE 265.—Construction of plastic prosthesis for ischial-bearing (above-knee) prosthesis for amputation through thigh. All bonding was accomplished with thermosetting resin. A. Thigh container and socket made from thermosetting resin and fiber glass. The socket could also be made of wood. B. Same, with molded socket inserted into thigh container and bonded. C. Longitudinal section of plastic container with plastic socket made from mold of short stump.

in length were necessary, a section of the fiber above the knee joint was removed and the knee was reattached. A simple leather liner was inserted in the fiber socket.

FIGURE 266.—Army type ischial-bearing prosthesis, of plastic or fiber, with pelvic belt, hip joint, and metal knee assembly.

In the more permanent type of prosthesis, the ischial-bearing socket was constructed according to a standard pattern, but its exact size depended upon the circumference of the stump, to which it was repeatedly fitted until it attained the proper size and contour. Special care was taken in molding the region of the ischial tuberosity, the greater trochanter, and the adductor tendon.

To control rotation of the limb, it was necessary that the ischial seat project inward. It was also necessary, for satisfactory sitting, that the back of the socket be somewhat flat. When sitting was uncomfortable, it was sometimes necessary to remove a portion of the socket posteriorly and replace it with a soft insert of leather and felt.

Wooden sockets were cut from blocks of seasoned willow, either by hand or by machine. The wall was left very thick until fitting was completed and the inside was finished. Then the outer excess of wood was cut away until there was left only a thin shell that resembled the normal thigh in size and shape. Metal parts were countersunk in the wood. The knee was alined and attached to the container or lower thigh section and then to the shin piece. If a plaster mold of the stump was available, the

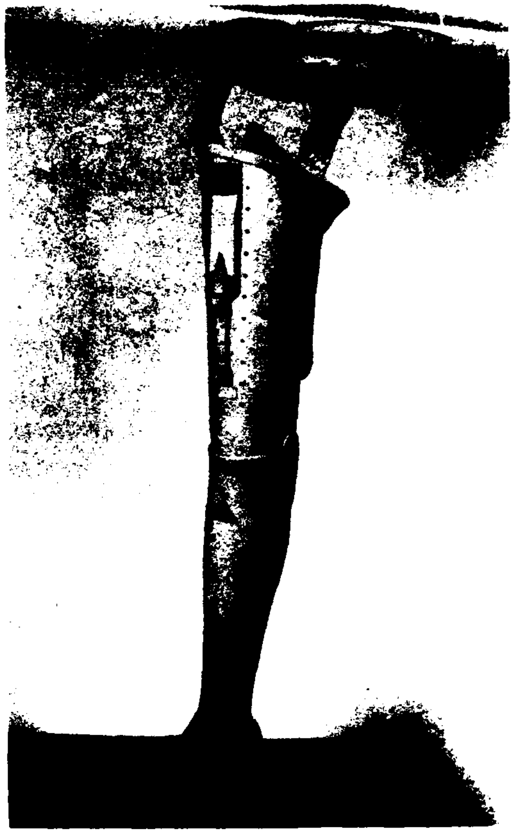

FIGURE 267.—Conventional prosthesis (Hanger) for mid-thigh amputation, with weight-bearing carried almost entirely on ischium. Note leather and elastic strap that helps to control knee motion.

socket could be cut on a duplicating machine that produced an exact counterpart of the model.

Fiber sockets were usually continuous to the knee joint. Plastic and metal sockets were united to separate thigh containers of the same material. The socket for a metal prosthesis could be metal or wood (fig. 267), depending upon the preference of the amputee. Metal sockets were made according to pattern, measurements, and trial fittings.

Since the socket would fit the stump correctly in only one position, the container and knee mechanism were fastened to it in that position. When realinement was necessary, the socket was detached and rotated or angulated into the desired new position.

Short thigh stumps were often fixed in flexion or abduction. It was the practice to fit stumps in the position of the deformity and make compensatory alterations between the socket and the knee. If allowance was

not made for his deformity, the amputee would stand with the lumbar spine in lordosis and the pelvis tilted, to hold the prosthesis stable on the ground.

If a straight thigh socket was fitted to a stump with a flexion deformity, its long axis would be the same as that of the stump itself, and the knee joint would extend far out in front of the body. Moreover, the foot would not approach the ground unless the spine was made to compensate by lordosis, as in ankylosis of the hip with flexion deformity. The same reasoning applied in the fitting of an abduction deformity: The prosthesis would protrude laterally unless abduction was compensated for by alinement, which could be accomplished by curving the socket and the thigh section, so that the patient could stand without deformity, with both feet together on the floor. In longer stumps, in which, fortunately, deformities were less frequent, the correction was accomplished with more difficulty.

The shoulder harness originally used in the ischial-bearing prosthesis resulted in poor gait and was ruled obsolete during the war. It was replaced by a pelvic belt and metal hinge (fig. 266). The belt, made of leather, was 3 or 4 inches wide and was reinforced by sheet aluminum or steel for the attachment of the hinged joint. The hinge, of heavy construction, was of either the single- or the multiple-action type. The multiple-action joint provided abduction-adduction in addition to flexion and extension, and while it lacked stability, it had greater flexibility and could be worn with more comfort.

The center of the hip joint was placed just above, and anterior to, the greater trochanter, at a point that coincided as nearly as possible with the axis of rotation of the hip. It was more difficult to fit a hip joint suspension than a harness, but much of the performance and comfort of the amputee depended upon a successful fitting.

Knee Joint

In providing for the knee joint in above-knee amputations, certain physiologic facts had to be borne in mind:

> In the normal knee, extension is accomplished by the quadriceps mechanism and flexion by the knee flexors. Stability, whether in standing or walking, depends chiefly upon the quadriceps muscle. If this muscle is weak or paralyzed, stability depends upon a position of hyperextension. As the extremity is thrust forward by the flexors of the hip and the extensors of the knee, extension is gradually and smoothly arrested by the braking action of the knee flexors.

In the artificial knee, extension is produced by a pendulum action initiated at the hip, assisted by an elastic strap or roller mechanism synchronized with hip motion (fig. 267). Extension of the knee is limited by both the mechanical arrangement and the rubber bumpers that halt

the motion in a position of slight hyperextension. On weight-bearing, the artificial knee must be in slight hyperextension in order to be stable. The necessary hyperextension of the knee depends upon (1) the location of the center of the knee joint; (2) the backward pressure induced by the hip extensors, principally the gluteus maximus; and (3) the upward pressure of the forefoot, which pushes the shin backward.

An ideal mechanical knee joint would permit weight-bearing at various degrees of flexion, but a device of this kind was not available during the war. This was unfortunate, for stability of the knee was a problem of special importance to the new amputee during the training stage of his recovery.

The knee section of the prosthesis in above-knee amputations was usually made as a separate unit and then bonded to the shin and thigh sections, by mechanical means or by a bonding agent. It was constructed from wood or from a metallic aluminum casting made by precision methods in several different sizes. Standardization that permitted interchangeability of parts was a desirable feature in the knee section as well as in other parts of the prosthesis.

Shin Section

The shin section for an ischial-bearing prosthesis was made of wood, aluminum, fiber, or plastic, and was as light as was consistent with the strength and durability required of it. It was contoured to correspond with the shape of the normal leg. The upper end was shaped to permit full flexion and extension of the knee block.

Ankle and Foot Sections

The ankle and foot were those used in other lower extremity prostheses.

Section V. Amputations at the Hip Joint

GENERAL CONSIDERATIONS

Wounds of the hip joint caused by missiles constituted an exceedingly difficult problem for several reasons:

Anatomically, important intrapelvic organs, including the rectum and the bladder, as well as large arteries and veins, are located so close to this joint that one or more of these structures was frequently injured by the same missiles that caused the injuries of the hip. The casualty was often in serious or critical condition, and vascular and visceral injuries necessarily took precedence over orthopedic injuries. As a result,

FIGURE 268.—Open amputation at left hip joint. Appearance of stump 4 weeks after operation. Conservation of more skin would have been desirable. Skin grafting was necessary for coverage. Subsequent plastic revision was required before satisfactory fitting of a prosthesis was possible.

initial wound surgery on the hip was often inadequate, and as a further result, suppurative arthritis was a frequent complication of these wounds. The incidence of complications was greatest when the missile damaged the articular surfaces of the head of the femur and the acetabulum. In such wounds, disarticulation was often the only feasible procedure.

Conservation of skin was of great importance in open amputations near the hip because in this region, it was difficult to obtain closure by traction (fig. 268).

When fractures of the femur were complicated by vascular damage and gas gangrene developed, amputation through the hip joint was a life-saving procedure. Initial disarticulation of the joint occasionally was necessary following trauma in the Zone of Interior. It was also required in a small number of bone tumors. About 80 disarticulations of the hip joint are known to have been performed by U.S. Army surgeons in World War II.

When subperiosteal removal of bone was part of the initial amputation, the remaining periosteum usually proliferated. Some amputees ar-

rived in the Zone of Interior with extensive bony proliferation, large amounts of degenerated and infected muscle tissue, and very painful stumps. Others arrived with cellulitis or draining sinuses. Procedures instituted to correct these conditions were the same as those indicated in any area in which drainage, revision, or plastic repair was required.

The ideal hip stump, when healed, presented a buttock nearly equal in size and contour to its fellow. The skin was smooth, rounded out, and free from sulci and redundancy. The suture line was located as far from the rectum as possible, for hygienic reasons. Lacking was the redundant or excessive muscle ordinarily recommended as a cushion; an excess of muscle or other soft parts tended to make the seat insecure, and the tissues were liable to pinching by the prosthesis.

TECHNIQUE

When reamputation of the hip was required by development of gas gangrene in the thigh, it was often possible to make the saw line through the neck of the femur or just below the greater trochanter. A disarticulation of the hip joint and an amputation through the neck of the femur or just below the greater trochanter produced comparable results, but the lower level was preferred. In amputations through the neck of the femur, the femoral head was left in the acetabulum, and dead space was obliterated by muscle tissue. In amputations below the greater trochanter, the stump was somewhat broader and the saw line was near the level of the ischial tuberosity or the weight-bearing point of the stump (fig. 269).

Disarticulation of the hip.—The anterior racket incision was the approach of choice in disarticulation of the hip:

The incision for the handle began at the middle third of Poupart's ligament and extended downward about 3 inches. The femoral artery was doubly ligated, after which the leg was elevated to drain the blood from it before the vein was ligated. Care had to be taken to ligate the common femoral artery above its division into superficial and deep branches, to avoid troublesome bleeding later in the operation.

The incision was next extended downward toward the inner aspect of the thigh, about 3½ inches below the perineum; was swung backward across the thigh to its posterior middle aspect; curved upward, crossing the greater trochanter; and continued across the anterior aspect of the thigh to a point 2 inches below the upper end of the incision, thus concluding the formation of the handle.

Next, the incision was carried down through the fascia. An attempt was made to include all sinuses present in the portion of the extremity to be resected if the flaps could be so modified as to accomplish this.

The thigh was adducted and internally rotated. The muscles over the greater trochanter were sectioned. The hip was extended, and the muscles on the medial and anterior aspects were cut near their origin from the pelvis. The joint capsule was incised at the femoral neck, and the hip was dislocated by abduction and rotation. The head of the femur was lifted forward, and, with a long amputating knife, the muscles and other soft parts were cut on the posteromedial surface from above downward and backward. The knife emerged at the line of the skin incision. Bleeders were clamped as they were cut.

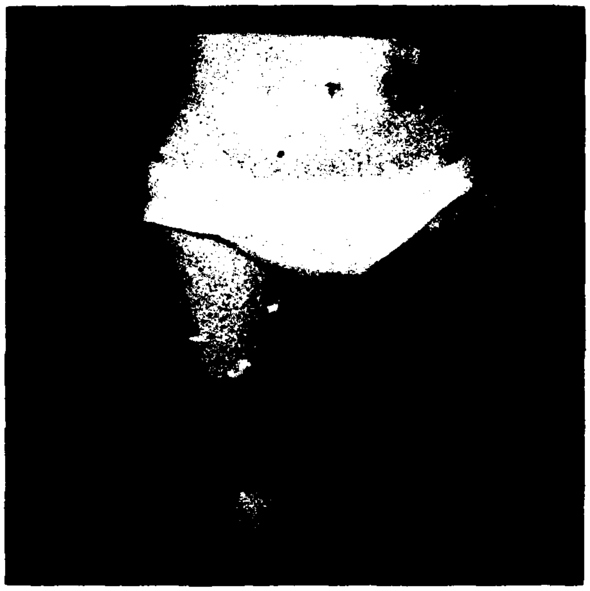

FIGURE 269.—Amputation through trochanteric area level with perineum. Amputation at this level is preferable to disarticulation.

The long posteromedial skin flap thus created included a thin layer of muscle and fascia. If the flap cut from within outward was too thick, it was revised. A large amount of residual muscle was objectionable; often, it became a mass of scar tissue that was difficult to remove.

Ligamentous tissue was excised from the acetabulum, and sinus tracts were dissected out. The sciatic and femoral nerves were isolated, pulled down, ligated, and cut so that they would retract well above the end of the stump.

When the wound had to be left open, it was covered with several layers of fine mesh gauze impregnated with petrolatum, and then with massive dressings. Skin traction was applied to the flaps. When closure was possible at the operation, as in a definitive amputation for tumor or in a secondary revision, it was accomplished in two layers. Drainage was instituted through the incision or through a separate stab wound. Postoperative dressings were carried out only as necessary.

Amputation through the neck of the femur.—When it was possible to make the saw line through the neck of the femur, the technique just described was modified accordingly. When the bone was exposed, the Gigli saw was passed behind the femoral neck, with the leg adducted and internally rotated, after the adductors and muscles inserted into the greater trochanter had been sectioned.

Subtrochanteric amputation.—When amputation just below the trochanter was elected, the skin-fascia incision was carried slightly lower on the posterior surface of the thigh and below the greater trochanter. The adductor muscles were cut as in the disarticulation operation, although not quite so close to their origin. The tensor fasciae femoris was cut so that it would retract to the saw line. The muscles inserted into the greater trochanter were not disturbed. The anterior group of muscles were cut

FIGURE 270.—Amputees at Walter Reed General Hospital Amputation Center, Washington, D.C., fitted with aluminum (tilting-table) prostheses after disarticulation at hip joint. The molded leather pelvic socket is supported in a metal frame, and the knee joints can be locked as desired.

to retract to the saw line. The posterior group and other soft parts were cut in circular fashion from behind, just below the fold of the gluteus maximus, so that they would also retract to the saw line. Then, the bone was sawed through in the usual manner.

PROSTHESES

Since little shrinkage occurs in disarticulation of the hip and similar procedures, a provisional prosthesis was not required, and amputees who had undergone these operations were fitted early and permanently (fig. 270), practically all of them at the Walter Reed General Hospital Amputation Center.

The prosthesis used after disarticulation was essentially a socket that fitted the hemipelvis.[3] After amputation at the level of the perineum, the stump was too short to be fitted with a thigh socket of the usual type, and it was found more satisfactory to carry out the fitting with the amputee seated and the stump flexed at a right angle.

The prosthesis consisted of a pelvic socket, a thigh piece, a shin piece,

[3] Why this prosthesis was generally known as the tilting-table prosthesis is not clear. It did not tilt, nor did it resemble a table.

and a foot of the usual type. The socket, which was usually made of heavy leather rigidly molded over a plaster cast of the pelvis, resembled a half segment of a bucket with a rounded bottom. Designed to carry the pelvic stump, it extended medially almost to the midline in front, and upward to the crest of the ilium. It was made low enough in front to avoid undue pressure on the abdomen when the man was seated. It was held up by a light steel frame that supported the body weight and provided an attachment for the hip joint.

The socket was fastened by straps around the opposite side of the pelvis, to maintain its position. Shoulder suspension was used as necessary to secure the socket more firmly to the stump. The position of the socket did not change in reference to the pelvis. The amputee sat in it whether he was sitting or standing.

The hip joint consisted of a wide hinged mechanism or of a simple hinge combined with a track upon which the thigh piece rotated about the socket. It was essential that the medial aspect of the socket be firmly supported by attachment to the thigh section. The posterior surface of the thigh section was cut away sufficiently to prevent interference with sitting.

The hip joint contained a lock that could be released manually and that locked automatically on extension. When he was ready to sit down, the amputee released the lock, which permitted the hip joint to flex. As he became more proficient in the use of his prosthesis, he was able to dispense with both hip lock and knee lock except for special occasions.

The knee mechanism was similar to that used in the thigh prosthesis. It contained a lock that the patient could use at will for standing and walking, but that had to be released for sitting.

References

1. Discussion on amputations, annual meeting, American Orthopaedic Association, Hot Springs, Va., 3 June 1944. J. Bone & Joint Surg. 26: 669–671, October 1944.

2. Circular Letter No. 189, Office of The Surgeon General, 17 Nov. 1943, subject: Emergency Surgery of the Extremities.

APPENDIX

Schedule of Special Treatment Course in Orthopedics

Surgery of the Extremities, University of California Medical School, 24 May–19 June 1943

Date	Time	Subject	Doctor in charge	Location
Monday, 24 May	0800–1200....	Anatomy	Saunders Abbott Schottstaedt	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
	1300–1600....	Application splints and plaster.	Dillon Schottstaedt	Rm. 237, Clinic Bldg.
	1600–1700....	Anatomy	Schottstaedt	Laboratory; Anat. Dept.
Tuesday, 25 May	0800–1700....	Treatment of fractures; practical demonstrations.	Bost Dresel Cox Anderson Gill	San Francisco County Hosp.
Wednesday, 26 May	0800–1700....			
Thursday, 27 May	0800–1700....	Anatomy	Saunders Abbott Lambert Eising	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
Friday, 28 May	0800–1200....	Anatomy	Saunders Abbott Carpenter	Univ. Calif. Hosp. Rm. 347, Clinic Bldg.
	1300–1600....	Application of splints and plaster.	Dillon Lambert	Rm. 327, Clinic Bldg.
	1600–1700....	Anatomy	Lambert	Laboratory; Anat. Dept.
Saturday, 29 May	0800–1200....	Anatomy	Saunders Abbott Sanderson	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
Monday, 31 May	0800–1200....	Anatomy	Saunders Abbott Hagey	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
	1300–1600....	Application of splints and plaster.	Dillon Carpenter	Univ. Calif. Hosp.
	1600–1700....	Anatomy	Carpenter	Laboratory; Anat. Dept.
Tuesday, 1 June	0800–1700....	Treatment of fractures; practical demonstrations.	Bost Dresel Cox Anderson Gill	San Francisco County Hosp.
Wednesday, 2 June	0800–1700....			

Surgery of the Extremities, University of California Medical School, 24 May–19 June 1943—Continued

Date	Time	Subject	Doctor in charge	Location
Thursday, 3 June	0900–1700	U.S. Naval Hospital	Hook, Mazet, Viera, Harral	Oak Knoll, Oakland, Calif.
Friday, 4 June	0800–1200	One-half of class to library to read literature on amputations, the other half to laboratory in Department of Anatomy for dissection instruction.	Schottstaedt	
	1300–1600	Application of splints and plaster.	Dillon, Sanderson	Univ. Calif. Hosp. Rm. 237, Clinic Bldg.
	1600–1700	Anatomy	Sanderson	Laboratory; Anat. Dept.
Saturday, 5 June	0800–1200	One-half of class to library to read literature on amputations, the other half to laboratory in Department of Anatomy for dissection instruction.	Lambert	
Monday, 7 June	0800–0930	Causes and treatment of delayed union and nonunion.	Haldeman	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
	0930–1030	Roentgenograms	Miller	Do.
	1030–1200	Amputations—hand	Blackfield	Do.
	1300–1600	Application of traction and splints.	Dillon, Lambert	Rm. 237, Clinic Bldg.
	1600–1700	Anatomy	Lambert	Laboratory; Anat. Dept.
Tuesday, 8 June	0800–1700	Treatment of fractures; practical demonstrations.	Bost, Dresel, Cox, Anderson, Gill	San Francisco County Hosp.
Wednesday, 9 June	0800–1700			
Thursday, 10 June	0900–1700	U.S. Naval Hospital	Owen, Holman, Toffelmier, Norcross, Pendleton	Mare Island, Vallejo.

Surgery of the Extremities, University of California Medical School, 24 May–19 June 1943—Continued

Date	Time	Subject	Doctor in charge	Location
Friday, 11 June	0800–0930	Acute and chronic infection of bone.	Haldeman	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
	0930–1030	Roentgenograms	Miller	Do.
	1030–1200	Refrigeration in surgery of the extremities.	Montgomery	Do.
	1300–1600	Application of skeletal traction and splints.	Dillon Schottstaedt	Rm. 237, Clinic Bldg.
	1600–1700	Anatomy	Schottstaedt	Laboratory; Anat. Dept.
Saturday, 12 June	0800–0900	Use of skeletal traction and operative fusion in fractures and dislocations of the cervical spine.	Lambert	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
	0900–1000	Roentgenograms	Miller	Do.
	1000–1200	Anesthesia in surgery of the extremities	Hathaway	Do.
Monday, 14 June	0800–0930	Treatment of osteomyelitis.	Shumate	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
	0930–1030	Roentgenograms	Miller	Do.
	1030–1200	Amputations	Inman	Do.
	1300–1700	To be announced.		
Tuesday, 15 June	0800–1700	Treatment of fractures; practical demonstrations.	Bost Dresel Cox Anderson Gill	San Francisco County Hosp.
Wednesday, 16 June	0800–1700			
Thursday, 17 June	0900–1700	Letterman General Hospital.	Patterson	Presidio, San Francisco.
	a.m.	Peripheral nerve problems. Program by Lt. Col. Patterson	Naffziger	
	p.m.	Program by Lt. Col. Patterson		
Friday, 18 June	0800–0930	Septic infections of joints and fractures of the pelvis.	Haldeman	Univ. Calif. Hosp. Rm. 437, Clinic Bldg.
	0930–1030	Roentgenograms	Miller	Do.
	1030–1200	Amputations	Inman	Do.
	1300–1700	Review	Abbott	Do.
Saturday, 19 June	0800–0900	Fractures and dislocations of the spine.	Haldeman	Do.
	0900–1000	Roentgenograms	Miller	Do.
	1000–1200	Amputations	Inman	Do.

INDEX [1]

[1] Unless otherwise specified, all items in this index pertain to orthopedic surgery, in the Zone of Interior, and in World War II.

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Source material for—
  bone grafts, experimental studies on, 406–409
  training injuries, 227
Sources of injuries of spine, 825
South Pacific Areas (SPA):
  Consultant in Orthopedic Surgery in, 381
  meniscectomy in, 673n
Southern France, invasion of, 380
Southern Surgical Association, 445
Southwest Pacific Area (SWPA), 322
  Consultant in—
    Orthopedic Surgery in, 381
    Surgery in, 381
  evacuation of casualties from, 257
  status of returned casualties from, 270–271

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